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MINERALOGY.

MINERALOGY.

BY

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Author of "An Introduction to the Study of Petrology."

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PREFACE.

MINERALOGY, which in the early days of British Geology was a favourite pursuit, has suffered some neglect in the latter part of this century—a neglect which, no doubt, is partly to be attributed to the rapid development and general culture of the biological sciences. Notwithstanding the attractiveness of the study of *life* in its manifold variety, an ignorance of the characters and properties of the *inanimate* products of Nature, on the part of those who cultivate the natural sciences, is to be deprecated, especially in a country that draws its chief wealth from its mineral resources. A knowledge of mineralogy is evidently essential to the miner: its acquisition should precede the study of geology, and accompany that of chemistry: while in itself the science may be made to serve as an excellent training for the eye, the hand, and the judgment.

Taking this view of its importance and being aware of the want of a popular introduction to the subject, I have willingly responded to Messrs. Whittaker's request that I should add a volume on MINERALOGY to their "Library of Popular Science."

It is my pleasing duty to acknowledge Messrs. Macmillan's courtesy in permitting me to reproduce figures that have appeared in books published by their firm.

Some of the illustrations are taken from photographs of specimens in the Museum of Practical Geology.

F. H. H.

28, JERMYN STREET, S.W.
Feb., 1892.

MINERALOGY.

PART I.

CHARACTERS OF MINERALS.

THE study of the visible portion of the earth's solid crust by the geologist has firmly established the fact that it is chiefly made up of material which is either of igneous origin, having consolidated from a molten state, or consists of sediments that have accumulated at the bottom of former seas and now lie piled up one above the other in strata many thousands of feet thick. These rock masses, whether igneous or sedimentary, consist of the inorganic substances known as **Minerals**. Besides those which unite to form rocks, there is a great variety of other minerals filling chinks and fissures in the crust, and comprising, *inter alia*, many of the valuable ore-deposits which are the source of our metals.

It is the business of the mineralogist to study the chemical and physical properties of these different kinds of mineral matter, and to classify them according to the facts thus elicited.

In accordance with this principle, this little book has been divided into two parts, of which the present part deals with the characters, or "physiography," of minerals,

and the succeeding part with their classification and description.

The characters of minerals afford a means by which the different species may be recognized and discriminated. They may be conveniently studied under the following principal heads:

Form,	Hardness,
Chemical Composition,	Cleavage,
Specific Gravity,	Fracture,

And Phenomena relating to Light.

I. Form.

In studying the properties of mineral matter, one of the first things that strikes the observer is the frequency with which it occurs in geometrical forms bounded by plane surfaces. In these bodies, which are termed **Crystals**, the component particles of matter are arranged in accordance with certain fixed laws of symmetry, this orderly mode of aggregation being evidenced by the fact, that the physical properties of the crystal are found to bear a definite relation to its external geometrical boundaries.

Mineral matter having the property of forming crystals is said to be *crystalline*. In some minerals, however, the aggregation of the molecules is subservient to no law of symmetry; and in these there is consequently no inter-dependence between physical structure and external form. This is known as the *amorphous* state of matter.

It must be borne in mind, however, that a crystalline

mineral need not always present a definite geometrical form. The environment of the crystal during its formation may have militated against the assumption of geometrical contours; but the crystalline or non-crystalline nature of a mineral will be always indicated by its physical structure, in consequence of the relations between form and structure already referred to.

The structure of mineral masses when crystallized is determined by the extent to which certain of the bounding planes (*faces*) of the crystals are developed at the expense of others. Such structures are the following:

Tabular (or platy, leafy, etc.),
Prismatic (or columnar),
Acicular (or needle-shaped),
Capillary (or hair-like).

When the mineral is amorphous or minutely crystalline, it assumes an external form which is bounded by other than plane surfaces. Such forms are designated by the following terms:

Massive,
Nodular,
Globular,
Botryoidal (like a bunch of grapes),
Mammillated,
Reniform (or kidney-shaped),
Granular,
Stalactitic (pendent),
Filiform,
Wiry,
Mossy.

In addition some minerals show an internal fibrous or concentric laminated arrangement of material; thus, a mammillated or globular external form may be associated with an internal fibrous structure, as in iron-pyrites and hæmatite.

FIG. 1.—MOSSY COPPER.

The study of crystals is termed **Crystallography.**

On examining a sufficiently large number of crystals, we find that they show differences in the symmetrical arrangement of their faces; and this can be utilized as a means of classification. Every crystal possesses what is termed *centrosymmetry*, *i.e.*, it has a centre of symmetry, through which a line drawn at right angles to any given face will meet another similar face also at right angles at the same distance on the other side of it.[1] But the *degree* of symmetry in a crystal is variable, and is measured by the number of its planes of symmetry. A *plane of symmetry* is a plane dividing a body into two parts, each of which is the exact but inverse counterpart of the other, that is to say, the two parts bear to one another the same relation that an image bears to its object, the mirror being equivalent to the plane of symmetry (see fig. 2). A line going through the centre of the crystal, and perpendicular to a plane of sym-

FIG. 2.—A PLANE OF SYMMETRY.

[1] Except certain hemihedral and hemimorphic crystals (see p. 24).

metry, may be termed an *axis of symmetry*. The fundamental law which underlies crystallography is the *law of symmetry*. It may be formulated thus: Every face of a crystal must possess a corresponding face parallel to it

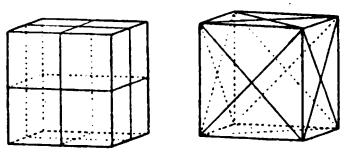


FIG. 3.—FORM WITH NINE PLANES OF SYMMETRY.

on the opposite side of the centre of symmetry, and there must also be faces corresponding to these on the opposite sides of the planes of symmetry, and making equal angles with them respectively. A group of faces

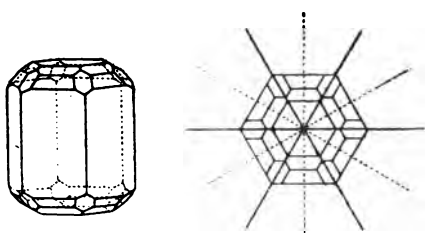


FIG. 4.—HEXAGONAL FORM, WITH SEVEN PLANES OF SYMMETRY. VIEW AND PROJECTION.

which are mutually related in accordance with this law is technically described as a *form*.

The number of planes of symmetry furnishes a ready means of classifying crystals. The greatest number of planes of symmetry possible in a crystal is *nine*. All forms which possess nine planes belong to the REGULAR or CUBIC system of crystals. Three of these planes are

perpendicular to one another, and six bisect the angles between each pair of the first (see fig. 3).

The remaining systems are the following: the HEXAGONAL, with *seven* planes of symmetry, six of which inter-

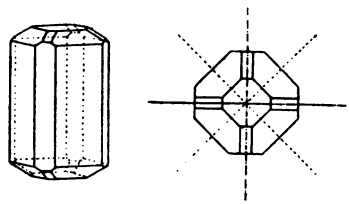


FIG. 5.—TETRAGONAL FORM, WITH FIVE PLANES OF SYMMETRY.

sect in one straight line, and are inclined to one another at an angle of 30°, the seventh being perpendicular to the other six (see fig. 4).

The TETRAGONAL, with *five* planes, four of which inter-

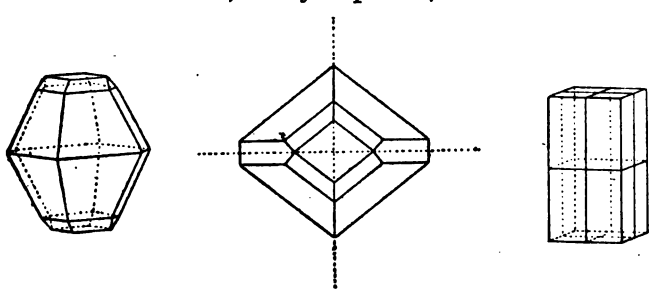


FIG. 6.—RHOMBIC FORMS, WITH THREE PLANES OF SYMMETRY.

sect in one straight line, and are inclined to one another at an angle of 45°, the fifth being perpendicular to the other four (see fig. 5).

The RHOMBIC, with *three* planes of symmetry perpendicular to one another (see fig. 6).

The MONOCLINIC, with *one* plane of symmetry (see fig. 7).

The TRICLINIC, or ASYMMETRIC, with no planes of symmetry (see fig. 8).

Classified according to their symmetry, there are thus six systems of crystals. The rhombohedral forms are

FIG. 7.—MONOCLINIC FORM, SHOWING ONE PLANE OF SYMMETRY.

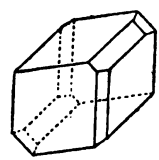
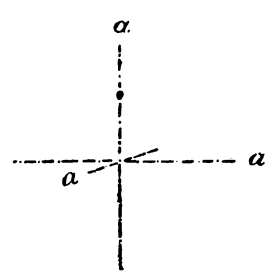


FIG. 8.—TRICLINIC CRYSTAL, WITH NO PLANE OF SYMMETRY.

considered by some to constitute a distinct system, with three planes of symmetry, intersecting in one straight line and inclined to one another at an angle of 60°. They are usually treated, however, as hemihedral derivatives of the hexagonal pyramids. (See *Hemihedrism.*)

The Regular System of Crystals.



This system comprises the following forms, which may occur alone or in combination: the octahedron, the cube, the rhombic dodecahedron, the icosi-tetrahedron, the triakis-octahedron, the tetrakis-hexahedron and the hexakis-octahedron.

For the purpose of comparison these forms are referred

to three equal axes standing at right angles to one another (and at right angles to the three principal planes of symmetry).

The *octahedron* is the simplest form of the regular system. It is composed of eight faces, each of which is an equilateral triangle, and cuts the three axes at unit distance. The angle between any two adjacent faces measured across an edge is 109° 28′ (see fig. 9).

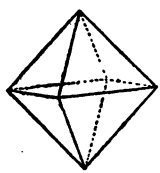


FIG. 9.—OCTAHEDRON.

The *cube* is another simple and very common form of this system. It is contained by six square faces, each of which cuts one axis at right angles, and runs parallel to the other two, thus coinciding in direction with the principal planes of symmetry. The angle between two faces measures 90° (see fig. 10).

The *rhombic dodecahedron* is contained by twelve equal

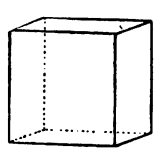


FIG. 10.—CUBE.

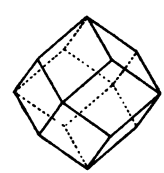


FIG. 11.—DODECAHEDRON.

rhombs (the diagonals of which bear to one another the ratio of $1 : \sqrt{2}$). Each face cuts two axes at unit distance, and is parallel to the third. The remaining six planes of symmetry of the regular system coincide in direction with the faces of this form. The

angle between two adjacent faces measures 120° (see fig. 11).

The *icosi-tetrahedra* are a series of forms contained by twenty-four deltoids (a plane quadrilateral figure bounded by pairs of adjacent equal straight lines). Each face cuts one axis at unit distance, the other two at a distance measured by a rational quantity, *m*. The series is limited on the one hand by the cube, on the other by the octahedron (see fig. 12).

The *triakis-octahedra* are a series of forms contained by twenty-four isosceles triangles. Each face cuts two axes

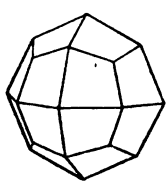


FIG. 12.—ICOSI-TETRAHEDRON.

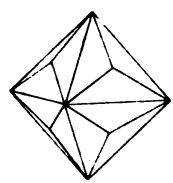


FIG. 13.—TRIAKIS-OCTAHEDRON.

at unit distance, the third at a distance equal to a rational quantity, *m*, greater than unity. The series is limited on the one hand by the octahedron, and on the other by the rhombic dodecahedron. The form is also known as the *pyramidal octahedron;* this designation has reference to the shape, which is that of an octahedron with a three-faced pyramid on each face (see fig. 13).

The *tetrakis-hexahedra* are a series of forms contained by twenty-four isosceles triangles. Each face cuts one axis at unit distance, one at a distance equal to a rational quantity, *m*, and is parallel to the third. The series is limited by the cube and the rhombic dodecahedron. The form is

also termed the *pyramidal cube*, from the fact that it can be described as a cube, each face of which is surmounted by a four-faced pyramid (see fig. 14).

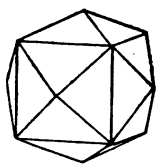


FIG 14.—TETRAKIS-HEXAHEDRON.

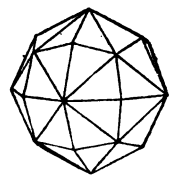


FIG. 15.—HEXAKIS-OCTAHEDRON.

The *hexakis-octahedra* are a series of forms contained by forty-eight scalene triangles. Each face cuts one axis at unit distance, another at a distance equal to a rational

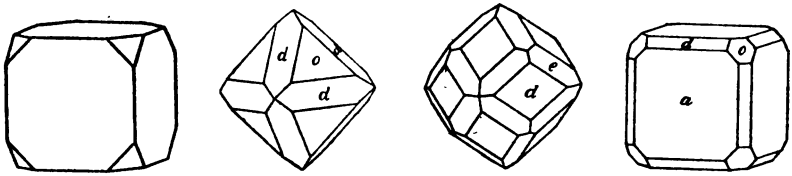


FIG. 16.—COMBINATIONS.

a. Cube.
o. Octahedron.
d. Dodecahedron.
e. Icosi-tetrahedron.

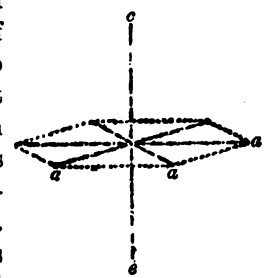
quantity, *m*, and the third at a distance equal to a rational quantity, *n*. By the variation of the values for *m* and *n*,[1] the hexakis-octahedron may be made to approximate suc-

[1] These letters, *m* and *n*, are used to denote the value of the intercept, or distance cut off on the axis by the face, reckoning from the point of origin. They represent any rational number, such as 1, 2, 3, or $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, etc.

cessively to all the simpler forms of the system. It is therefore the most general of all the forms of the Regular system (see fig. 15). For examples of the various combinations of simple forms, see fig. 16.

The Hexagonal System.[1]

The forms belonging to this system are referred to four axes, three of which (a) are equal and similar, and cross one another at an angle of 60°, while the fourth (the chief axis c) is unequal and dissimilar to the other three, and stands at right angles to the plane formed by them (see fig. 17). The ratio of a to c is an irrational number, to be determined for each particular mineral. It represents the relative lengths of the intercepts of the pyramid chosen for the fundamental form. Thus in quartz the ratio $a : c = 1{\cdot}0999$. The most important forms are the pyramids, the prisms and the basal plane. The pyramids are obtuse or acute, being limited on the one hand by the basal plane, on the other, by the prism.



The *proto-pyramids*, or *pyramids of the first order*, are a series of forms contained by twelve isosceles triangles, each of which cuts two of the lateral axes at the unit distance, is parallel to the third, and cuts the vertical axis at a distance equal to c multiplied by a rational quantity, m (see fig. 17). When m is infinitely small (*i.e.*, equals 0) we have

[1] So called on account of the horizontal section being a hexagon.

the *basal plane*, when m becomes infinitely large (*i.e.*, equals ∞) we get the *proto-prism*. The basal plane is thus parallel to the lateral axes and at right angles to the

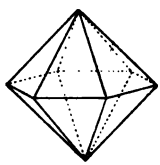


FIG. 17.—PROTO-PYRAMID.

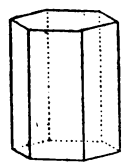


FIG. 18.—PROTO-PRISM.

vertical. The proto-prism is a form composed of six parallel to one lateral axis, and to the vertical. Both forms can only occur in combination, and are often associated with one another (see fig. 18).

The *deutero-pyramids*, or *pyramids of the second order*, are a series of forms, each of which is contained by twelve isosceles triangles, cutting one of the lateral axes at the unit distance, the remaining two at a distance equal to twice the unit length, and the vertical axis at a distance equal to c multiplied by a rational quantity, m. This series is also limited by the basal plane and the deutero-prism.

The *dihexagonal pyramids* are a series of pyramids contained by twenty-four scalene triangles. Each face cuts one lateral axis at the unit distance, and another at a distance equal to a multiplied by a rational quantity, n, which must be less than 2; while the vertical axis is intercepted at a distance represented by mc. There is a corresponding *dihexagonal prism*, in which the intercept on the vertical axis is infinitely great, *i.e.*, its faces are

parallel to this axis. For examples of the combinations of simple forms see fig. 19.

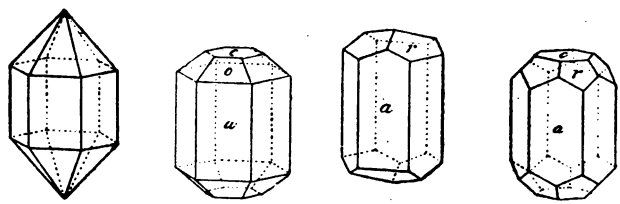
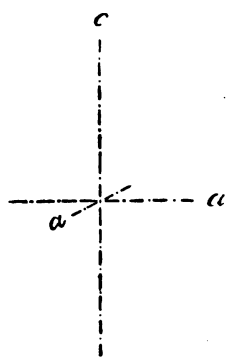


FIG. 19.—COMPOUND FORMS.

c, basal plane. *a*, prism.
o, pyramid. *r*, rhombohedron (see p. 25).

The Tetragonal System.[1]

The forms of this system are referred to three axes at right angles to one another, two of which (*a*) are equal, the third (the vertical axis, *c*) unequal. As in the Hexagonal system, we have pyramids and prisms of two orders (a *proto* and a *deutero* series); but in this system the pyramids consist of eight faces and the prisms of four, instead of twelve and six respectively. There is also a ditetragonal pyramid, consisting of sixteen faces. The basal plane is parallel to the lateral axes, as in the Hexagonal system. The proto-pyramids cut the lateral axes at the unit distance,



[1] So called on account of the horizontal section being a tetragon or square.

and the vertical at a distance equal to *mc*. When *m* equals infinity the form becomes the proto-prism. The

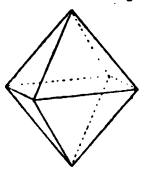


FIG. 20.—PROTO-PYRAMID.

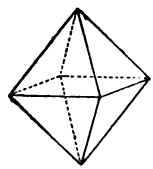


FIG. 21.—DEUTERO-PYRAMID.

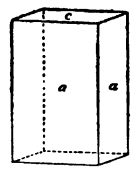


FIG. 22.—DEUTERO-PRISM.

deutero-pyramid cuts one lateral axis at right angles, and is parallel to the other; while the vertical is cut at a

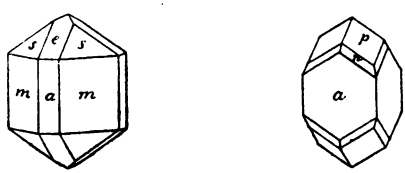


FIG. 23.—TETRAGONAL COMBINATIONS.

s and *p*, proto-pyramids. *m*, proto-prism.
e, deutero-pyramid. *a*, deutero-prism.

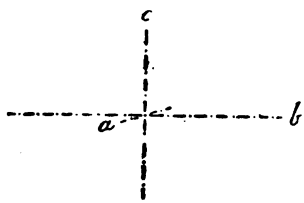
distance equal to *mc*: by increasing the value of *m* we approximate to the deutero-prism.

For examples of the combinations of simple forms, see fig. 23.

The Rhombic System.

The forms of this system are referred to three unequal and dissimilar axes, which stand at right angles to one another. One of these (*c*) having been chosen for the

vertical, the shorter of the two laterals (the *brachy-diagonal, a*) is directed towards the observer, while the larger (the *macro-diagonal, b*) is then transverse.



The forms comprise pyramids, prisms, domes, and pinacoids, of which the last three can only be seen in combination.

Starting from a fundamental pyramid which cuts the three axes at the unit distance,[1] we derive various pyramids, according as we increase or diminish the distance cut off on the vertical, the macro- and the brachy-axes. Thus, besides the fundamental series, we get two series of pyramids, a brachy series and a macro series, each series being limited by the corresponding prism, brachy- or macro-prism, as the case may be.

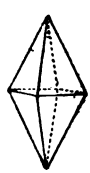


FIG. 24.—A RHOMBIC PYRAMID.

The *domes*[2] are forms comparable to the prisms, but differing from them in being parallel to a lateral instead of to a vertical axis. Like the prisms they may be regarded as special cases of the pyramids, *i.e.*, as pyramidal faces that cut one of the

[1] It must be borne in mind that the unit of measurement is different for *each* axis in the Rhombic and succeeding systems. The ratio of the intercepts of the fundamental form, which is chosen for each particular mineral, is $a : b : c$, or, if b be taken as unit, $a : 1 : c$; a and c being irrational. Thus the ratio of the intercepts of the pyramid, chosen as the fundamental form for sulphur, is ·813 : 1 : 1·9037; or $a : b : c$ = ·813 : 1 : 1·9037.

[2] So called on account of their giving a roof-like termination to crystals.

lateral axes at an infinite distance: they are, in fact, the lateral limiting forms of the brachy- and macro-diagonal series of pyramids respectively, just as the prisms are the limiting forms of the pyramids in a vertical direction. The brachy-dome cuts the macro-axis and the vertical axis, and runs parallel to the brachy-axis; the macro-dome, on the other hand, cuts the brachy-axis and the vertical axis, and runs parallel to the macro-axis.

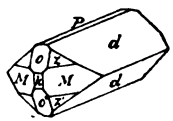


FIG. 25.
COMBINATION—
P, basal plane.
z, pyramid.
k, macro-pinacoid.
M, prism.
d, brachy-dome.
o, macro-dome.

FIG. 26.
COMBINATION—
m, macro-dome.
b, brachy-pinacoid.

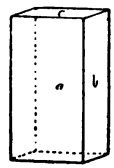
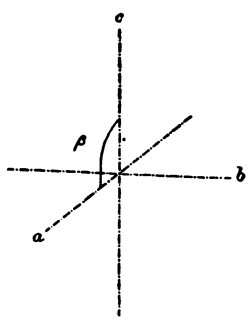


FIG. 27.
COMBINATION—
c, basal plane.
b, brachy-pinacoid.
a, macro-pinacoid.

The *pinacoids* are faces which cut one axis perpendicularly, and are parallel to the other two. In this sense the basal plane may be regarded as a pinacoid. The true pinacoids are two in number, namely, the brachy-pinacoid, parallel to the vertical and the brachy-axis, and the macro-pinacoid parallel to the vertical and the macro-axis. For compound forms, see figs. 25, 26, and 27.

The Monoclinic System.

The forms of this system are referred to three unequal and dissimilar axes: of these one is at right angles to the other two, which cut one another obliquely. The crystals are conventionally so placed that the observer looks into the obtuse angle (β) formed by the inclined axis with the vertical. The inclined axis is termed the *clino-*



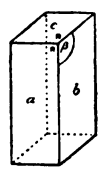


FIG. 28.—MONOCLINIC COMBINATION OF—
c, basal plane.
b, clino-pinacoid.
a, ortho-pinacoid.
β is the angle between the axes *a* and *c*; *R*, *R* are right angles.

axis (or *clino-diagonal*, *a*); while the perpendicular axis is known as the *ortho-axis* (or *ortho-diagonal*, *b*). The one plane of symmetry of this system contains the vertical and the inclined axes. It is represented as a crystal face by the clino-pinacoid (see fig. 28). In consequence of there being only one plane of symmetry a pyramid, or more correctly *hemi-pyramid*, in this system consists of four faces instead of eight; two at the top, front (−) or back (+), and two at the bottom, back (−) or front (+).

As in the Rhombic system, the forms comprise pyramids, prisms, domes, and pinacoids. These are classi-

fied according to their relation to the axes. Thus, besides the fundamental pyramid with unit values for the lateral axes, and those derived from it by the variation of the intercept on the vertical axis (the lateral

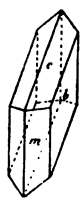


FIG. 29.—MONOCLINIC COMBINATION OF—
c, pyramid.
m, prism.
b, clino-pinacoid.

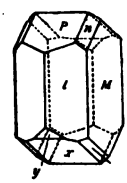
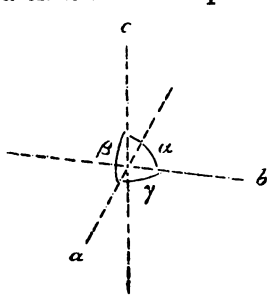


FIG. 30.—COMBINATION OF—
p, basal plane.
n, clino-dome. *l*, prism.
M, clino-pinacoid.
x and *y*, ortho-domes.

axes being in this series cut at unit distance), there is an ortho- and a clino-series of pyramids, an ortho- and a clino-series of prisms and domes, and the two pinacoids—the ortho-pinacoid and the clino-pinacoid. The terminal or basal plane is parallel to the two lateral axes. See fig. 17.



The Triclinic System.

The forms of this system are referred to three unequal and dissimilar axes which intersect obliquely. These axes are placed so that one axis is vertical (*c*), and the lateral axes are inclined from back to front (*a*), and from left to right (*c*).

There is no plane of symmetry, and the simple forms consist only of the two parallel faces required by the law of centro-symmetry. Being open forms they can only occur in combination.

Here again the forms include pyramids, prisms,

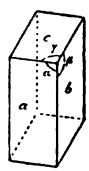


FIG. 31.—TRICLINIC COMBINATION OF—

c, basal plane. *b*, brachy-pinacoid. *a*, macro-pinacoid.

The angles between the common edges of these faces are equal to those between the axes, namely, α, β, and γ.

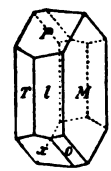


FIG. 32.—TRICLINIC COMBINATION.

P, basal plane.
o, pyramid.
T and *l*, prisms.
M, brachy-pinacoid.
x, macro-dome.

domes, and pinacoids, constituting macro- and brachy-series, as in the Rhombic system. Fig. 32 represents a combination, consisting of basal plane (P), brachy-pinacoid (M), two prisms (T and *l*), a macro-dome (x), and a pyramid (o).

Symbols.[1]

The use of symbols to designate the forms and faces of crystals is so general, that a few words on the subject will not be inappropriate here. There are two principal methods in vogue, namely, those of Naumann and

[1] This section should be omitted by the general reader, unless he wishes to obtain some knowledge of the nature and use of symbols in crystallography.

Miller. Naumann's system is considered by some to be characterized by an attractive simplicity, especially for the beginner; but the Millerian system is better adapted for mathematical treatment. In the former system (Naumann's) the fundamental form is designated by an initial letter—thus O stands for the octahedron of the Regular system, and P for the fundamental pyramid of the remaining systems. Other forms are represented by the addition to these letters of coefficients, including the sign for infinity (∞). When placed before the initial letter (*e.g.*, *m*P) these coefficients indicate what multiple of the intercept of the fundamental form is cut off by the faces of the form in question on the vertical axis; but when they follow the letter, they refer to one of the lateral axes (*e.g.*, P*m*). The length of the intercept on one of the axes being always reduced to the unit value, it is only necessary to give the intercepts on two axes. Thus *m*P*n* indicates a form that cuts off intercepts equal to *mc* on the vertical and *na* or *nb* on one lateral, the intercept on the third axis being the unit distance.

In the Rhombic and Triclinic systems, where it is necessary to distinguish between the long and short lateral axes, the signs — and ˘ are used for this purpose by placing them above the initial letter. Thus $\bar{\text{P}}m$ indicates a form that cuts off *mb* on the macro-axis, the intercepts on the two other axes being unity, while $\breve{\text{P}}m$ is a form with an intercept of *ma* on the brachy-axis.

In the Monoclinic system, again, we have to distinguish between a perpendicular and an inclined axis. This is done by placing a bar straight or obliquely through the initial letter. Thus $\not{\text{P}}m$ indicates that *m* refers to the ortho-axis, while in $\not\not{\text{P}}m$ it refers to the clino-axis.

In the Millerian system the symbol is composed of the "indices" of the face. These are obtained by converting the multiples of the three fundamental intercepts, for a given face, into fractions, of which the numerator is in each case 1: the denominators of these fractions are then the "indices." Thus a face of which the ratio for the intercepts is $1a : 2b : 3c$, will have indices represented by the denominators of the fractions $\frac{1}{1}$, $\frac{1}{2}$, and $\frac{1}{3}$; and 632 will be its Millerian symbol. The symbol for the form of which 632 is one face, is (632). Naumann's symbol for this form would be $3\bar{P}2$ in the Rhombic system.

The symbols of some of the principal forms, according to both systems, are given in the following table. The first column shows the multiples of the fundamental intercepts on the three axes.

Regular System.

Name of Form.	Multiples of a a a	Naumann.	Miller.
Octahedron . . .	1 1 1	O	(111)
Cube	1 ∞ ∞	∞ O ∞	(100)
Rhombic dodecahedron	1 1 ∞	∞ O	(110)
Icosi-tetrahedron .	1 m m	m O m	$(h\,l\,l)$[1]
Hexakis-octahedron .	1 n m	m O n	$(h\,k\,l)$

[1] The letters h, k, and l are used in the Millerian symbols to represent any whole numbers, just as the coefficients m and n re-

Hexagonal System.

Name of Form.	Multiples of $a\ a\ a\ c$	Naumann.	Miller.[1]	Bravais.
Basal plane .	$\infty\ \infty\ \infty\ 1$	o P	(111)	(0001)
Pyramids . .	$1\ \infty\ \bar{1}\ m$	m P	(hkk, eff)	$(h\ o\ \bar{h}\ l)$
Prism . . .	$1\ \infty\ \bar{1}\ \infty$	∞ P	$(2\bar{1}1)$	$10\bar{1}0$
Rhombohedron		R	$(h\ l\ l)$	

Tetragonal System.

Name of Form.	Multiples of $a\ a\ c$	Naumann.	Miller.
Basal plane . . .	$\infty\ \infty\ 1$	o P	(001)
Pyramids	$1\ 1\ m$	m P	$(h\ h\ l)$
Deutero-pyramids .	$1\ \infty\ m$	m P ∞	$(h\ o\ l)$
Prism	$1\ 1\ \infty$	∞ P	(110)
Deutero-prism . .	$1\ \infty\ \infty$	∞ P ∞	(100)

present any rational numbers in Naumann's system. The relation between $h\ k\ l$ and $m\ n$ may be expressed thus: $m : n = \frac{h}{l} : \frac{h}{k}$.

[1] In Miller's Notation the three edges of a rhombohedron (p. 25) are taken as axes.

Rhombic and Triclinic Systems.

Name of Form.	Multiples of *a*	*b*	*c*	Naumann.	Miller.
Basal plane . . .	∞	∞	1	o P	(001)
Pyramids	1	1	*m*	*m* P	(*h h l*)
Brachy-pyramids . .	*n*	1	*m*	*m* $\breve{P}$ *n*	(*h k l*) *h* < *k*
Macro-pyramids . .	1	*n*	*m*	*m* $\bar{P}$ *n*	(*h k l*) *h* > *k*
Prism	1	1	∞	∞ P	(110)
Brachy-domes . . .	∞	1	*m*	*m* $\breve{P}$ ∞	(o *k l*)
Macro-domes . . .	1	∞	*m*	m $\bar{P}$ ∞	(*h* o *l*)
Brachy-pinacoid . .	∞	1	∞	∞ $\breve{P}$ ∞	(010)
Macro-pinacoid . .	1	∞	∞	∞ $\bar{P}$ ∞	(100)

Monoclinic System.

Name of Form.	Multiples of *a*	*b*	*c*	Naumann.	Miller.
Basal plane . . .	∞	∞	1	o P	(001)
Pyramids	1	1	*m*	*m* P	(*h h l*)
Clino-pyramids . .	*n*	1	*m*	*m* $\breve{\mathbf{P}}$ *n*	(*h k l*) *h* < *k*
Ortho-pyramids . .	1	*n*	*m*	*m* $\bar{\mathbf{P}}$ *n*	(*h k l*) *h* > *k*
Prism	1	1	∞	∞ P	(110)
Clino-domes . . .	∞	1	*m*	*m* $\breve{\mathbf{P}}$ ∞	(o *k l*)
Ortho-domes . . .	1	∞	*m*	*m* $\bar{\mathbf{P}}$ ∞	(*h* o *l*)
Clino-pinacoid . .	∞	1	∞	∞ $\breve{\mathbf{P}}$ ∞	(010)
Ortho-pinacoid . .	1	∞	∞	∞ $\bar{\mathbf{P}}$ ∞	(100)

Modifications in the Symmetry of Crystals.

The symmetry of the forms of the different systems is subject to certain modifications, resulting in hemihedrism, hemimorphism, and twinning. In the first two

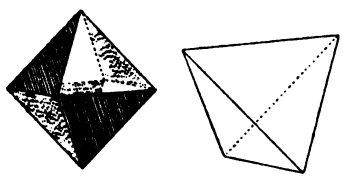


FIG. 33.—OCTAHEDRON AND TETRAHEDRON,
The suppression of the shaded faces in the former gives rise to the latter form.

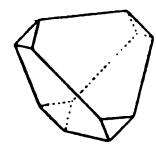


FIG. 34.—TETRAHEDRON,
With its corners truncated by a second tetrahedron.

cases the degree of symmetry is diminished; in the last it is often increased.

Hemihedral forms are those which possess only half

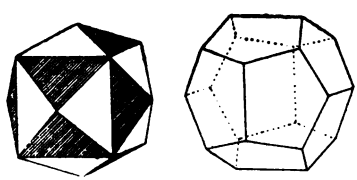


FIG. 35.—PENTAGONAL DODECAHEDRON,
Derived from the tetrakis-hexahedron by the suppression of the shaded faces.

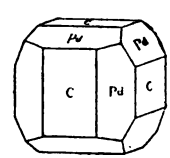


FIG. 36.—PENTAGONAL DODECAHEDRON, (*Pd.*)
In combination with the cube, *c*.

the full number of faces required by the symmetry of the system to which they belong. Such forms can best

be understood by reference to a full-faced (holohedral) form. The suppression of alternate faces, or groups of faces in the holohedral form gives rise to a hemihedral derivative of that form. Thus the hemihedral derivative

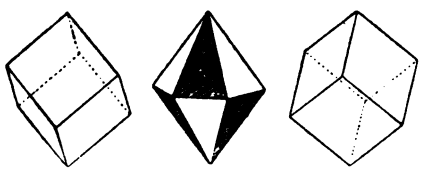


FIG. 37.—TWO KINDS OF RHOMBOHEDRA,
Derived by the suppression of alternate faces of the hexagonal pyramid.

of the octahedron is the *tetrahedron*, composed of four equilateral triangles, as exemplified in an important silver-copper-ore (tetrahedrite). Another example in the Regular system is the *pentagonal dodecahedron*, which may be derived from a corresponding tetrakis-hexahedron, by the suppression of alternate faces.

Fig. 36 shows a combination of the pentagonal dodecahedron with the cube, often found in iron-pyrites.

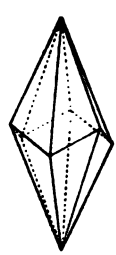


FIG. 38.—SCALENOHEDRON.

The hexagonal pyramid is also subject to hemihedrism, giving rise to the *rhombohedron*, a six-faced form characteristic of the minerals calcite, dolomite, spathic iron-ore (see fig. 37). The dihexagonal pyramid gives rise similarly to the *scalenohedron* (see fig. 38), and the tetragonal pyramid to the sphenoid.

Hemimorphism, on the other hand, is a property possessed

by certain crystals of presenting different forms at the opposite ends of an axis of symmetry (generally the vertical axis), instead of being terminated similarly at both ends as in normal crystals. The phenomenon of hemimorphism is closely connected with that of pyro-electricity, since those minerals which are hemimorphic acquire positive and negative electricity at the ends or *poles* of the hemimorphic axis when warmed or cooled, *e.g.*, tourmaline and hemimorphite (silicate of zinc).

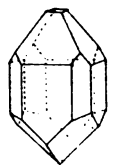


FIG. 39.—HEMIMORPHITE.

A **twin** is, as its name implies, a double crystal. The examination of a twin shows that it consists of two individual crystals, or two parts of one and the same individual, united on a common plane, or penetrating one another symmetrically. To explain this phenomenon, it is necessary to refer the two individuals to a plane—the *twinning plane*—with regard to which both are symmetrically disposed.[1] Now it is found that the two twinned individuals can be brought into a position of complete parallelism if one of them be rotated through an angle of 180° on an axis (the *twin axis*, $t\,t'$ in fig. 40) perpendicular to the twinning plane. The plane which unites the two individuals (the *plane of composition*) is often, but not necessarily, coincident with the plane of twinning. In some cases the two individuals completely penetrate one another, as in figs. 41, 42, and 44. These types can also be explained by a hypothetical rotation of one individual about a twin axis.

One of the most characteristic features of twinned

[1] Note that the twinning plane can never be a plane of symmetry of the *individual* crystal *if it is holohedral.*

crystals is the presence of re-entrant angles, whereas the angles of simple crystals are always solid. Twinning frequently results in the production of knee-shaped (geniculated), arrow-headed, cross- and heart-shaped forms, as in

FIG. 40.—TWINNED CRYSTAL,
Produced by the rotation of one-half through an angle of 180° round the axis, *t t'*.

the minerals tin-stone, gypsum, and staurolite (figs. 43, 44, and 45). Sometimes the same type of twinning is repeated

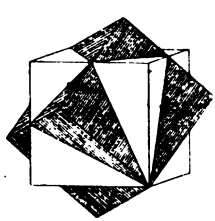


FIG. 41.—CUBES TWINNED BY INTERPENETRATION.

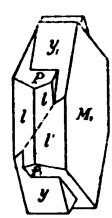


FIG. 42.—TWO MONOCLINIC CRYSTALS TWINNED BY INTERPENETRATION.

in one and the same crystal, producing what is termed *polysynthetic* or lamellar twinning, the lamellæ sinking occasionally to mere striations, as in plagioclase felspar. In some cases the compound crystal has a higher degree of symmetry than the simple individuals; thus rhombic

and monoclinic minerals sometimes assume when twinned a pseudo-hexagonal form, *e.g.*, aragonite and tridymite.

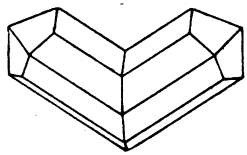


FIG. 43.—GENICULATED TWIN OF TINSTONE.

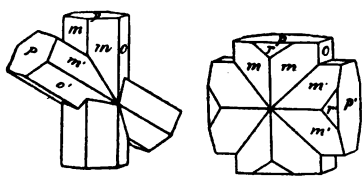


FIG. 44.—CROSS-SHAPED TWINS OF STAUROLITE.

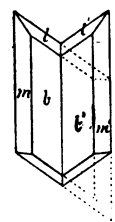


FIG. 45.—ARROW-HEADED TWIN OF GYPSUM.

The dotted part shows the position of the rotated half in the untwinned crystal.

Pseudomorphism.

In the mineral kingdom there are certain substances which possess the form of one mineral, while exhibiting the internal structure of another. These remarkable bodies are termed **pseudomorphs**. Although arising from various causes, they are all due to some secondary process acting on the original mineral in such a way as to remove or decompose its substance, while retaining its external contours. Pseudomorphs are classified according to their mode of origin. Quartz is sometimes found in crystal-forms characteristic of the mineral calcite and tinstone in the form of felspar: these are pseudomorphs produced by *replacement*, molecule by molecule.

Galena, which is sulphide of lead crystallizing in the Regular system, is occasionally found presenting the crystal form of pyromorphite (phosphate of lead crystallizing in the Hexagonal system): this is a case of pseudomorphism produced by chemical *change*. Other pseudomorphs are produced by *incrustation*, *i.e.*, the deposition of one mineral in regular layers on the faces of already existing crystals of another.

II. Chemical Composition.

Minerals are either simple *elementary* substances such as gold, sulphur, and the diamond, or they consist of *compounds* of the elements in certain fixed proportions.

Without trespassing too far on the domains of chemistry, we may briefly mention that the elements are divided by chemists into *metals*, of which the most important are gold, platinum, silver, copper, tin, mercury, iron, aluminium, zinc, manganese, barium, calcium, magnesium, potassium, and sodium; and *metalloids* or *non-metals* such as oxygen, sulphur, phosphorus, chlorine, fluorine, carbon, silicon.

With regard to the *compound* substances occurring as minerals, these are mostly either compounds of the metals with oxygen (oxides), or with sulphur (sulphides); or they are metallic salts of the acids—sulphuric acid (sulphates), carbonic acid (carbonates), hydrochloric acid (chlorides), fluoric acid (fluorides), phosphoric acid (phosphates), boracic acid (borates), and silicic acid (silicates). Hydrogen, in combination with oxygen (H_2O), also enters into the combination of a great number of minerals as "water of crystallization."

The compound which plays by far the largest part in the constitution of the earth's crust is silicon dioxide or silica (*i.e.*, a compound of silicon with oxygen, SiO_2), which either in the free state as quartz, or in combination with metallic bases as silicates, forms more than half the solid crust, and enters into the composition of nearly all the rocks of which it is composed. Next in importance is alumina, which is an oxide of aluminium. In union with silica this oxide constitutes the basis of a great series of aluminous silicates (felspar, mica, clay, etc.), which are the chief ingredients of a great number of rocks. Carbon dioxide (a compound of carbon with oxygen, CO_2) often appears in combination with lime or magnesia, forming immense deposits of limestone and dolomite.

Lime (oxide of calcium), as already stated, is present in limestone, and in gypsum in combination with sulphuric acid. Other compounds which largely enter into the composition of the rock-forming minerals are magnesia and the alkalies—potash and soda.

Iron and manganese play a part of some importance in many rocks. The oxides and salts of iron may be said to constitute Nature's colour-box; for the rich shades of yellow, red, and brown which are so effective in coast scenery, and are seen wherever bare rock is exposed, are chiefly due to iron. The deep chocolate colour of some soils, and the varied colours of sands, are to be ascribed to the same cause. The wide distribution of manganese in marine sediments has been demonstrated by the researches of Murray and Renard, lately published in the Reports of the "Challenger" expedition ("Deep-Sea Deposits").

Polymorphism.

There are several instances of minerals which differ in crystalline form and physical properties, but are identical in chemical composition. The property by which one and the same chemical substance has the power of appearing in two or more different states of molecular aggregation, is termed **polymorphism**. Calcite and aragonite (both carbonate of lime), and rutile, anatase, brookite (all titanic acid), are familiar instances. The former is a case of *dimorphism*, the latter of *trimorphism*.

Isomorphism.

Isomorphic minerals are those which, having a similar chemical composition, crystallize in identical or closely related forms; *e.g.*, calcite (carbonate of lime), dolomite (carbonate of lime and magnesia), and spathic iron ore (carbonate of iron), all of which crystallize in rhombohedral forms. The phenomenon of isomorphism points to there being a close connection between the atomic structure of the molecule and the arrangement of the latter in the structure of the crystal.

III. Specific Gravity.

By specific gravity is meant the weight of a unit volume. For the purpose of easy comparison water is taken as the standard (specific gravity of water = 1); and the specific gravity of a body is the ratio of the weight of a given

volume to the weight of the same volume of water. It is usually determined by weighing the body first in air and then in water: the difference is the weight of a mass of water equal in bulk to the body; and this difference divided into the weight in air is the specific gravity. Another method, which is very serviceable in cases where the specific gravity is not above 3·3, is to make use of one of the so-called "heavy solutions."[1] The concentrated solution is diluted, by the gradual addition of water, until a fragment of the mineral under examination remains just suspended. Its specific gravity is then determined either by weighing a measured volume, or by the Westphal's balance. By an adroit adjustment of the strength of such a solution, it may be used as a means of separating a mixture of minerals of different specific gravity, such as are found associated in rocks. An ingenious method of using the heavy solutions for this purpose has been devised by Professor Sollas.[2] It consists in the construction of a "diffusion-column:" a small glass tube being half-filled with the heavy fluid, water is poured in; after six or seven hours the two liquids will be found to have mixed in such a way that the density of the column increases uniformly downwards. Various horizons may then be marked in the column by the introduction of fragments of minerals of known density, each of which will float at that level where the specific gravity of the liquid is identical with its own. The density of any layer between these levels may be read off against a graduated mirror.

[1] Borotungstate of cadmium, or iodide of mercury dissolved in potassic iodide.

[2] "Nature," February 26th, 1891.

It is evident that the specific gravity of even the minutest particles may in this manner be easily determined.

On studying the specific gravity of minerals,[1] we find that the native metals rank as the heaviest: Gold varies from 15 to 19; platinum, 17—19; mercury, 13—14; lead, 11—12; silver, 10—11; copper, 8—9. Next come the metallic ores, *e.g.*, galena, 7·5; specular iron, 5·2; iron-pyrites, 5; magnetite, 5; tinstone, 4·5; zinc-blende, 4.

Among minerals that are not compounds of the heavy metals, barytes ("heavy spar") takes the first place with the specific gravity of 4. Fluorspar is 3·2; calcite (Iceland spar), 2·7; gypsum, 2·3; rock-salt, 2·1.

The gems vary from 2·2—4·6: opal, 2·2; emerald, 2·7; turquoise, 2·75; diamond, 3·52; topaz, 3·55; garnet (pyrope), 3·75; sapphire and ruby, 4; garnet (almandine), 4·2; zircon, 4·6.

The common rock-forming minerals range from 2·5 to 3·5: quartz, 2·6; augite, 3·4; hornblende, 3; mica, 2·8; felspars, 2·56—2·75; olivine, 3·4.

Thus it will be seen that the metallic ores betray themselves, even to the casual observer, by their great relative weight, a fact which is naturally of inestimable value. Among precious stones specific gravity is also of great importance, since it enables the jeweller to determine with certainty whether a given stone is really what its colour and general appearance may indicate.

The average density of the materials that make up the earth's crust is between 2·5 and 3. But since the density of the whole mass of the earth has been determined, by

[1] See Websky's "Die Mineral-Species nach den für das specifische Gewicht derselben angenommen und gefundenen Werthen." Breslau, 1868.

the oscillation of the pendulum and other physical methods, to be about 5·5, we are impelled to the conclusion that the interior of the earth must consist of a specifically heavier nucleus than the crust which covers it. Possibly there is a greater proportion of the metallic minerals in those inaccessible regions. One important fact in accord with this view should be noted, namely, that the relative rarity of the native metals is in direct proportion to their specific gravity.

IV. Hardness.

The term hardness signifies the resistance offered by a body to the separation of its particles. The relative hardness of minerals may be utilized as a means of identification. It is measured by the force required to scratch (*i.e.*, to separate the superficial particles of) the mineral with a steel point or the sharp-pointed fragment of some mineral harder than the one to be experimented upon. The results obtained from one and the same mineral are found to vary slightly with the crystal-face, and even with the direction in one and the same face. The relative *average* hardness of minerals may be expressed by reference to the following scale, devised by the Freiberg mineralogist, Mohs:

1. Talc.
2. Gypsum.
3. Calcite.
4. Fluorspar.
5. Apatite.
6. Felspar (adularia).
7. Quartz.

8. Topaz.
9. Corundum (sapphire).
10. Diamond.[1]

Each of these minerals can be scratched by those which follow it, and itself will scratch those that precede it in the scale.

Minerals having the hardness 1—2 can be scratched by the finger-nail; those lying between 3 and 5 by the point of the knife (with gradually increasing difficulty); 6 can scarcely be marked by the knife, but is touched by a steel file; 7 scratches glass; 8 scratches the steel file; while 9 is only to be scratched by the diamond.

Allied to the property of hardness, and depending also on the nature of the molecular cohesion, are those of tenacity and elasticity. They are manifested by the behaviour of a mineral when submitted to pressure, percussion, tension, torsion, or division. According to the results obtained the mineral is said to be *brittle*, *malleable*, *ductile*, *elastic*, or *sectile*. Haidinger found that the ductility of the metals, as shown by the ease with which they could be drawn into wire, decreased in the following order: gold, silver, platinum, iron, copper, zinc, tin, lead; and their malleability, as shown by the ease with which they could be flattened out under the hammer, as follows: gold, silver, copper, tin, platinum, lead, zinc, iron.

[1] These so-called "degrees of hardness" are only points arbitrarily fixed in a graduated scale. There is no constant ratio between the different numbers. Thus, the degrees of hardness of talc, gypsum, and calcite lie within much narrower limits than those of topaz, corundum, and the diamond.

V. Cleavage.

A piece of Iceland spar, when tapped with a light hammer, splits into a number of rhombohedral bodies of variable size but of similar form. A piece of rock-salt similarly treated splits into cubes. Mica, on the other hand, splits into thin laminæ. This property of crystals of separating along certain planes, related to the symmetry of the system to which the particular crystal belongs, is termed cleavage. It is one of the most striking of the physical properties of crystals, and one that gives important evidence as to the mode of aggregation of the crystal-particles: for the separation may be safely assumed to take place in the direction of least cohesion, *i.e.*, perpendicularly to that in which the particles exert their greatest attraction.[1]

Cleavage may be considered with regard to (1) quality or degree; (2) direction.

1. *Quality or degree.*—According to the force required to cause a crystallized mineral to split along its cleavage planes, we may distinguish between imperfect and perfect cleavage. A mineral possessing only an imperfect cleavage will, when broken, present a rough surface in which the planes of separation are frequently interrupted by cross fractures and continued on a different level. The complete parallelism of the separated portions of a cleavage-plane can be proved, however, by their being simultaneously illuminated when moved to and fro

[1] The cleavage of minerals is not to be confounded with that of rocks, which is a fissile structure due to the arrangement of the minerals constituting the rock, and not a molecular structure at all.

in a beam of light, in such a manner as to reflect the rays towards the eye of the observer. A mineral with perfect cleavage will split along faces which in many cases are more smooth and even, than the original faces of the crystal themselves.

2. *Direction.*—The planes of cleavage are always parallel to possible faces of the crystal; and the number of intersecting planes varies according to the number of faces which make up the form in question. Thus a mineral with octohedral cleavage will split in four different directions; with cubical, in three; with prismatic, in two (except in the Triclinic system); with pinacoidal, or basal, in one. Some minerals, however, possess cleavages parallel to the faces of more than one form, and these are then frequently to be distinguished by their different quality or degree of perfection.

A few examples of cleavage are the following:

Cubical: rock-salt, galena.
Octahedral: fluor-spar.
Rhombic dodecahedral: zinc-blende.
Pyramidal: sulphur.
Prismatic: hornblende.
Basal: mica, topaz.
Pinacoidal: gypsum.
Domatic: barytes.
Rhombohedral: the spars—calcite, dolomite, etc.
Two cleavages: felspar, barytes.

In all these cases the cleavage may be regarded as fairly perfect. Examples of imperfect cleavage may be found in the minerals augite and olivine.

VI. Fracture.

The nature of the surface produced by breaking a mineral is also a valuable diagnostic character. Fracture, as it is termed, must not be confounded with cleavage. The former can only be produced in a direction in which cleavage is not developed; consequently, if the tendency to cleave is strongly developed in a mineral it will be difficult to produce a true fracture.

The fracture of minerals may be described as *even*, *uneven* (as in quartz), *splintery*, and *hackly* (as in copper), and *conchoidal* (as in flint).

VII. Phenomena of Light.

Colour.

White light falling on a body is either completely reflected (1), completely transmitted (2), or a portion of the coloured rays of which it is composed becomes absorbed at the surface, and the remainder is either reflected (3) or transmitted (4). In case 1 the body is white and opaque; in case 2, white and transparent; in case 3, coloured and opaque; in case 4, coloured and transparent. The colour of a mineral is either an intrinsic property—as, for instance, that of gold, copper, cinnabar, ruby-silver; or it is accidental, and due to the inclusion or admixture of a small quantity of some colouring substance, as in rose-quartz, fluor-spar, some varieties of felspar (*e.g.*, the so-called amazon-stone) and most gem-stones. When powdered most minerals show a different colour to that which charac-

terizes them in the mass. This property is utilized as a test; namely, by filing off a little of the mineral, or by drawing the mineral across the rough surface of a piece of unglazed porcelain: the resulting mark is termed the *streak* of the mineral. The streak of a mineral is therefore the colour of its powder.

Pellucidity.

According to the amount of light transmitted we may distinguish between the *transparency*, *translucency*, and *opacity* of minerals. The pellucidity of a mineral is to a certain degree dependent on its colour; for a dark colour diminishes transparency. It is also influenced by the thickness of the specimen, some minerals which are opaque in thick pieces being translucent in thin plates or splinters. The opacity of minerals is not always an inherent quality, since in some cases it is the result of decomposition, hydration, etc. (*e.g.*, the kaolinization of felspar, and the serpentinization of olivine).

Lustre.

The lustre of a mineral is due, partly to the *degree* in which light is reflected, and partly to the *nature* of the reflected light. According to the quantity of light reflected, a mineral is said to be *splendent* (as blende), *shining* (as calcite), *glistening* (as magnetite), *glimmering* (as galena), or *dull* (as serpentine). According to the nature of the reflected light the lustre is *metallic* (as in the native metals, pyrites), *adamantine* (as in diamond and blende), *vitreous* (as in quartz), *greasy* (as in elæolite), *pearly* (as in diallage), or *silky* (as in tremolite).

There are a few other phenomena, produced either by peculiarities in the reflecting surface, or by the fact that reflection takes place from surfaces in the interior of the crystal. Such, for example, are the following. *Opalescence*, —a peculiar milky or cloudy appearance produced by the diffraction of light by minute fissures in the interior of a crystal (*e.g.*, opal, moonstone). *Chatoyancy*,—a changeable banded lustre like that of the eye of a cat. Chatoyant stones, like chrysoberyl ("cat's-eye"), when cut suitably flash out bands of light which shift their position according to the way in which the stone is moved. This phenomenon is the result of a fibrous structure. When two or three systems of striations intersect, a star composed of four or six luminous rays is produced. This phenomenon is termed *asterism*, and is displayed by certain varieties of ruby, sapphire, garnet, and mica. *Schiller*—is the name given to certain metallic and pearly lustres produced by the reflection from the surfaces of minute enclosed plates, rods, or particles (as in diallage, bronzite, hypersthene and aventurine). *Change of colours*—is a phenomenon of diffraction produced at the surface of some minerals by a fine lineation (*e.g.*, labradorite). *Iridescene* and *irisation* refer to the prismatic colours produced by the interference of light in the interior and at the surface of a mineral. In the former case the phenomenon is due to the presence of minute fissures, in the latter to the presence of a thin superficial film.

The phenomena which are connected with the double refraction and polarization of light cannot be discussed in a work of these dimensions. The reader is referred to the volume on "*Light*" of this series.

PART II.

CLASSIFICATION AND DESCRIPTION OF THE MINERALS.

THERE are several different ways of treating this part of the subject:—we may arrange the minerals according to the rôle played by them in the structure of the crust of the earth; we may consider them with reference to their economic importance; or we may adopt a chemical or a crystallographic classification. No doubt for many purposes the latter would be the most desirable; but our present purpose will be best served by a judicious combination of the first two methods.

Accordingly we will divide the minerals into four groups.

i. *The rock-forming minerals, i.e.,* the materials which constitute the greater portion of the earth's crust.

ii. *The ores, i.e.,* the metalliferous minerals that fill fissures or cavities in the crust of the earth, or occur in the form of stratified deposits on the surface, and are mined for the extraction of the metals; and the *veinstones* that accompany them.

iii. *The salts and useful minerals other than the ores, i.e.,* many of which find an important application in various branches of industry.

iv. *The gems or precious stones, i.e.,* the rare, hard, and lustrous minerals used for purposes of ornamentation and adornment.

I. THE ROCK-FORMING MINERALS.

Although no doubt the greater number of the rocks which constitute the visible portion of the earth's crust are of sedimentary origin, it is in the crystalline rocks that we must look for variety in mineral composition; and even those minerals that are found in the sedimentary strata are derived in great measure from rocks of igneous or metamorphic origin. The commoner constituents of the crystalline rocks are felspar, quartz, mica, hornblende, augite, and olivine; while chlorite, serpentine, calcite, dolomite, and kaolin (clay) are produced by their decomposition, and are termed *secondary minerals*. The relative proportion in which the minerals, composing the superficial crust of the earth, occur, has been roughly calculated to be as follows:

Felspar	48 %
Quartz	35 %
Mica, chlorite, talc, etc.	13 %
Hornblende, augite, olivine and serpentine	1 %
Carbonates of lime and magnesia	1 %
Clay (hydrated silicate of alumina)	1 %
Other substances (including ores, salts, etc.)	1 %

These numbers serve to give us a rough idea of the composition of the external layers of the earth. Lower zones have doubtless a different composition, and the basic silicates together with the heavy metals and their compounds play a more extended rôle (see p. 84).

The Felspars.

Under the name Felspar is included a series of closely allied minerals which, while varying in chemical composition and crystallizing in two systems (the Monoclinic and Triclinic), are similar in their physical characters and crystalline form. The crystal-faces usually present are: the basal plane (generally denoted by p), the clino- or the brachy-pinacoid (M), the prisms (l or t and l), the two ortho- or the two macro-domes (x and y), the clino- or the brachy-dome (n), and the pyramid (o).

Two well developed cleavages occur in felspar; of these the principal is in the direction of the basal plane

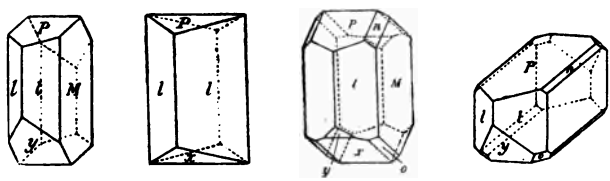


FIG. 46.—SOME OF THE COMBINATIONS IN WHICH ORTHOCLASE OCCURS.

P, basal plane. *l*, prism.
M, clino-pinacoid. *n*, clino-dome.
o, hemi-pyramid. *x* and *y*, ortho-domes.

(p); but this is nearly equalled by one parallel to M. These two planes of separation are at right angles to one another in monoclinic felspar, but make an angle varying from 86° 24′ to 85° 50′ in triclinic varieties. A third, but very imperfect, cleavage exists parallel to the faces of the prism. The surface of fracture in felspar is irregular to sub-conchoidal; the hardness, 6.

Monoclinic or **Orthoclase Felspar.** A silicate of alu-

mina and potash: K_2O, Al_2O_3, $6SiO_2$ (17 % K_2O, 18 % Al_2O_3 and 65 % SiO_2). With the exception of hydrofluoric no acids attack it. Its specific gravity varies from 2·54 to 2·57. The crystals show either a tabular or a columnar habit according to the relative development of faces. The basal plane (P) and the orthodome (x) are about equally inclined to the vertical, and produce a roof-like termination, the angle between the two faces being 129° 43′. Crystals of orthoclase are frequently twinned, most often on what is known as the Carlsbad type. In this the two individuals are usually united on the clino-pinacoid (M); and the basal planes (P) of the crystals are inclined in opposite directions, each being brought into close juxtaposition with the orthodome of the other individual. The relative position of the two individuals twinned on this type can be explained by an imaginary rotation of one of them about the vertical axis.

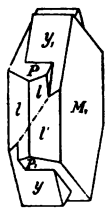


FIG. 47.—ORTHOCLASE TWINNED ON THE CARLSBAD TYPE.

When pure and free from inclusions orthoclase is colourless and transparent (*adularia*, *sanidine*); but more frequently it is opaque, being either white, flesh-coloured, or red. Although this opacity and colouration may in some instances be due to extraneous matter included in the crystal during its formation, it is more frequently the result of alterations produced by weathering. During this process the felspar substance undergoes chemical change, kaolin, or china-clay (silicate of alumina) being formed, while silica is set free in the form of quartz. In certain cases muscovite and talc are also products of its decomposition.

Orthoclase is an essential constituent of the more acid igneous rocks, such as granite, syenite, and felsite, also of the foliated granitic rocks or gneisses. The clear, glassy, and fissured variety, known as sanidine, is common in the volcanic rocks—rhyolites and trachytes. Among sedimentary rocks orthoclase occurs in felspathic grits and sandstones, which in most cases are derived directly from the waste of granitic rocks. It is also common as a vein-stone, being a chief constituent of the so-called pegmatites.

Triclinic or Plagioclase Felspars.—Silicates of alumina, lime, and soda, constituting series of lime-soda felspars, ranging from a pure lime-felspar (*anorthite*) to a pure soda-felspar (*albite*). The intermediate members (*oligoclase*, *andesine* and *labradorite*) have been shown to be isomorphous mixtures of albite and anorthite in varying proportions. The series is graduated not only in respect to chemical constitution, but also with regard to optical and other physical properties.

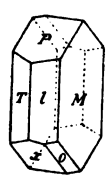


FIG. 48.—PLAGIOCLASE-FELSPAR.
P, basal plane.
M, brachy-pinacoid.
o, pyramid.
T and *l*, prisms.
x, macro-dome.

The composition of anorthite is represented by the formula $CaO, Al_2O_3, 2SiO_2$, which is equivalent to 20·1 per cent. of lime, 36·82 per cent. of alumina, and 43·08 per cent. of silica.

The chemical formula for albite is $Na_2O, Al_2O_3, 6SiO_2$, corresponding to 11·82 per cent. of soda, 19·56 per cent. of alumina, and 68·62 per cent. of silica.

The specific gravity of anorthite is 2·7; that of albite,

2·62. The felspars of intermediate composition have values for specific gravity lying between these two extremes. With regard to their chemical behaviour, albite, oligoclase, and andesine are not sensibly attacked by hydrochloric acid; but labradorite is slightly affected; while anorthite is decomposed with separation of gelatinous silica. The fusibility is greatest in albite, and least in anorthite.

The crystal-form of the plagioclase felspars is similar to that of orthoclase, with the difference that the basal plane (P), instead of being at right angles to the pinacoid (M),

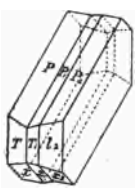


FIG. 49.—POLY-SYNTHETIC TWIN OF PLAGIOCLASE.

("Albite-type.")

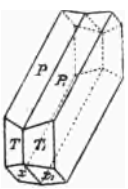


FIG. 50.—DUAL TWIN OF ALBITE.

P, basal plane of first individual.
P_1, ,, ,, second ,,

makes an angle with it of 94° 10′ in anorthite, and 93° 36′ in albite. A distinctive character of these felspars is their mode of twinning. It is not usually a dual or double type, as in orthoclase, but a repeated or polysynthetic arrangement of individuals, the crystal being divided into a number of parallel lamellæ, each of which is in the twinning position with regard to its immediate neighbours; alternate lamellæ, however, are similarly situated. This type of twinning is known as the albite type. The twinning-plane is the brachy-pinacoid (M),

or in other words, the structure of the twinned crystal can be explained by an imaginary rotation of alternate lamellæ about an axis normal to the brachy-pinacoid (M). The basal planes of all the lamellæ lie on the same side of the crystal, but slope alternately towards and away from one another so as to produce a series of parallel ridges and depressions, the general effect of which is a parallel striation parallel to M, which is best seen on the surfaces produced by the basal cleavage.

Plagioclase felspars occur in many igneous rocks, *e.g.*, in the intrusive diorites, gabbros, dolerites, and in the volcanic andesites, porphyrites and basalts. The variety oligoclase often accompanies orthoclase in granite and trachyte. Oligoclase and albite are also frequent constituents of the schists, occurring in them in a clear granular form in association with quartz (*secondary* or *granulitic felspar*).

Like orthoclase, plagioclase is prone to decomposition, giving rise to epidote, zoisite (in the so-called saussurite) calcite, and kaolin.

Quartz.

This mineral, which is characteristic of the acid group of igneous rocks and crystalline schists and is the chief constituent of sand, sandstone, and quartzite, consists of pure silica. It crystallizes in the Hexagonal (Rhombohedral) system. The crystals consist either of the double pyramid of twelve faces, or of this pyramid in combination with the prism of the same order. The faces of the prism are distinguished by a horizontal striation. Other and rarer faces also occur; indeed, so numerous are the different forms, and so varied their association, that

no two quartz crystals can be said to be absolutely identical.

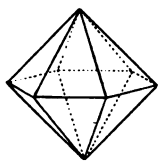


FIG. 51.—QUARTZ.
Bi-pyramidal crystal.

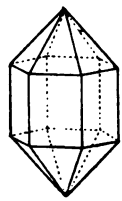


FIG. 52.—QUARTZ.
Pyramid in combination with prism.

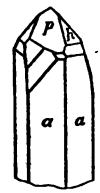


FIG. 53.—QUARTZ.
A characteristic complex of forms.

The crystals are frequently distorted, the distortion being of such a kind that some of the faces are unduly developed at the expense of their fellows, but in every case the angle between any two given faces always remains constant. One kind of distortion gives rise to what is known as *sceptre-quartz*.

FIG. 54.—A GROUP OF PELLUCID QUARTZ CRYSTALS.
(From a photograph.)

Quartz is not attacked by acids excepting hydrofluoric acid, and is insoluble in potash. Its specific gravity is 2·6; its hardness, 7. It possesses no cleavage, and its fracture is irregular to sub-conchoidal.

The mineral may be recognized by its hardness, pellucidity, and vitreous lustre. Usually it is quite colourless and transparent, but coloured and trans-

lucent varieties also occur, *e.g.*, brown or yellow (*smoky quartz*, *cairngorm*, *jasper*), pink (*rose-quartz*), purple (*amethyst*), green (*chrysoprase*), white and translucent (*milky quartz*). The pure crystalline variety is known as *rock-crystal*, and the crypto-crystalline variety as *chalcedony*.

The chief rocks in which quartz occurs are granite, quartz-porphyry, felsite, rhyolite, gneiss, mica-schist, quartzite, sand, sandstone, clay and shale. It is also a common companion of the ores, being a frequent vein-stone, or gangue material. Gold, when found in place, is almost invariably associated with quartz ("gold-quartz").

The Micas.

The micas are hydrated silicates of alumina and the alkalies, potash, soda, or lithia, with which iron and magnesia are associated in some varieties. They crystallize in the Monoclinic system, but possess pseudo-hexagonal symmetry. The crystals consist of six-sided tablets, of which the six sides are made up of the four faces of a prism, and two of the clino-pinacoid, the broad terminal faces being those of the basal plane. Parallel to the basal plane a very perfect cleavage is developed, permitting of the separation into laminæ of extraordinary thinness; it is characteristic for mica, as distinguished from other allied minerals (talc, chlorite), that these laminæ are elastic, and cannot therefore be permanently bent. The specific gravity varies from 2·76 to 3·2. The hardness is 2·3.

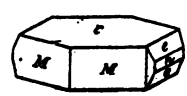


FIG. 55.—MICA-CRYSTAL.

c, basal plane.
M, prism.
h, clino-pinacoid.
e, clino-dome.

The micas may be conveniently separated into two broad sub-divisions: the *white* or *light-coloured*, and the *black* or *dark-coloured* varieties. Chief among the former is **Muscovite**, or **Potash-mica**, which is essentially a hydrated silicate of alumina and potash. This variety of mica is not attacked by hydrochloric acid. It occurs in flakes, scales, and laminæ of a silvery-white or golden-yellow colour, in many granites, gneisses and phyllites. Fragments are often present in sandstones and shales (derived, no doubt, originally from granitic rocks); and by their parallel arrangement impart to these rocks a fissile character.

The most important dark mica is **Biotite**, which is essentially a hydrated ferro-magnesian and aluminous silicate. Unlike muscovite, this mica is attacked by hot hydrochloric acid. It has a dark brown to black colour and metallic lustre. It occurs in granites and mica-traps and in certain syenites, diorites, trachytes, and andesites. Loose crystals of a reddish-brown biotite (rubellan) are frequently found imbedded in volcanic tuff. By decomposition mica readily passes into chlorite, assuming then a green colour.

The following is a list of the different varieties of mica:

Light Micas.

Muscovite, potash-mica.
Paragonite, potash-soda mica.
Margarite, lime-mica.
Lepidolite, Zinnwaldite } lithium-micas.

Dark Micas.

Biotite (including meroxene and lepidomelane).
Phlogopite.
Anomite.

THE HORNBLENDE AND AUGITE GROUP.

These minerals are silicates, mainly of magnesia and lime; but some varieties contain iron and alumina or

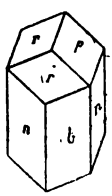


FIG. 56.—HORNBLENDE.

p, basal plane.
b, clino-pinacoid.
r, hemi-pyramid.
n, prism.

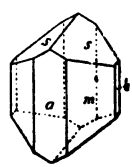


FIG. 57.—AUGITE.

a, ortho-pinacoid.
b, clino-pniacoid.
s, hemi-pyramid.
m, prism.

manganese, soda or lithia in addition. In the hornblendes, the magnesia predominates over the lime; but in the augites the reverse holds good, for the calcareous base is present in greater quantity than the magnesian. All the varieties resist the action of acids, excepting hydrofluoric. Their specific gravity varies from 2·90 to 3·55, their hardness from 5 to 6. The commoner species of both groups crystallize in the Mono-

clinic system, but Rhombic kinds also occur. The main feature distinguishing the hornblendes from the augites is the angle between the faces of the prism, which in hornblende measures 124°, in augite 87°.

The crystals are usually short-columnar, and consist of prisms and pinacoids, terminated by a pair of pyramidal faces. In the hornblendes the prism-faces usually predominate over the pinacoids, the ortho-pinacoidal

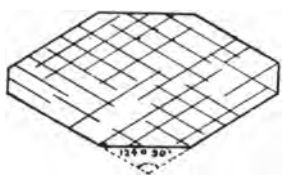


FIG. 58.—CROSS-SECTION OF A HORNBLENDE CRYSTAL,

Showing the lines of prismatic cleavage intersecting at an angle of 124°.

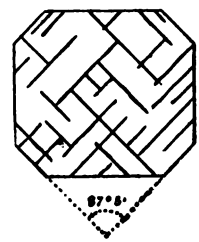


FIG. 59.—CROSS-SECTION OF AN AUGITE CRYSTAL,

Showing the lines of prismatic cleavage intersecting at an angle of 87°.

faces being often even absent; in augite, on the other hand, they are about equally developed. A cross-section of hornblende is consequently lozenge-shaped, but one of augite octagonal.

The crystals are occasionally twinned, namely, on the ortho-pinacoid. A cleavage exists in both minerals parallel to the faces of the prism. In hornblende it approaches a high degree of perfection, the cleaved surfaces being smooth and lustrous; but in augite it is far less perfect, and the surfaces produced are uneven.

The common variety of both groups is a shining black mineral; but green, blue, and white varieties also occur.

The following list includes the more important hornblendes and augites:

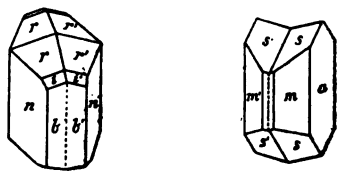


FIG. 60.—TWINNED CRYSTALS OF HORNBLENDE AND AUGITE.

Monoclinic Hornblendes.

Common Hornblende (black aluminous varieties).
Actinolite, Nephrite (green hornblendes).
Glaucophane, Riebeckite (blue soda-hornblendes).
Tremolite, Asbestos (white fibrous hornblendes).

Rhombic Hornblendes.

Anthophyllite (white and fibrous).

Monoclinic Augites.

Common Augite (black aluminous varieties).
Diopside, Omphacite, Salite, Diallage (green and white augites).

Rhombic Augites.

Enstatite, Bronzite, Hypersthene (white and brown augites with metallic lustre).

Common hornblende occurs in certain varieties of granite and syenite, also in diorite, trachyte, and andesite.

Actinolite is a hornblende of bright green colour, occurring in blades, needles, and fibres in hornblende-schists, amphibolites, and epidiorites. Nephrite forms a closely knit plexus of minute fibres and blades in the hard and tough substance which is so much prized under the name of *jade*. Tremolite occurs in metamorphic limestones. Asbestos is made use of in the arts on account of its fibrous texture and indestructibility by fire: thus it is employed in the manufacture of fire-proof material, engine-packing, etc.

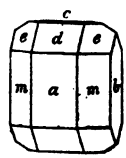


FIG. 61.—OLIVINE.

c, basal plane.
a, macro-pinacoid.
b, brachy-pinacoid.
e, pyramid.
m, prism.
d, macro-dome.

Common augite occurs in dolerite, basalt, and in certain trachytes and andesites. The green and white varieties are found in peridotites, and as an accessory constituent in some metamorphic limestones. Diallage is an essential constituent of gabbro; while the rhombic augites occur in some varieties of diorite, gabbro, dolerite, andesite, and peridotite.

OLIVINE.—This mineral is a silicate of iron and magnesia, belonging to the Rhombic system of crystals. When well crystallized, it occurs in tabular and pris-

matic forms, which are made up chiefly of pinacoids and domes. More frequently, however, it is found in irregular grains. Its specific gravity is 3·2—3·5; its hardness, 6·5—7. Treated with hydrochloric acid it gelatinizes. In colour it varies from olive-green to yellow. Certain yellowish-green and leek-green varieties are used as gem-stones, under the name of chrysolite and peridot.

Olivine may be recognized by its green colour, vitreous lustre, conchoidal fracture, and imperfect pinacoidal cleavage. As a rock constituent, it is characteristic of the basic and ultra-basic rocks, occurring in basalts, dolerites, and gabbros, and being the chief constituent of the peridotites.

Under the influence of the weather, and percolating waters, it is peculiarly liable to alteration, giving rise in some cases to serpentine and limonite, in others to dolomite or calcite.

Secondary Minerals.

Up to the present we have been considering those rock-constituents that have been produced by crystallization from a molten, or at least a plastic, condition; but a considerable proportion of the rocks that make up the earth's crust are composed of minerals that have been accumulated and deposited by water. Such, for instance, are the sandstones, clays, shales, and many limestones. The minerals composing these rocks are of earlier origin than the rocks themselves, being derived from other mineral aggregates or rocks by processes of disintegration and denudation. The latter, of course, may also have

been of aqueous origin, but if we could trace back the history of such a series of changes sufficiently far, we should arrive finally at a primary crust, which if formed under normal conditions, must necessarily have had an igneous birth. The part played by water in the disintegration and decomposition of a rock, and in the distribution and rearrangement of the materials thus produced, is best exemplified by a specific case. Granite is a rock composed chiefly of quartz, felspar, with a little mica or other ferro-magnesian constituent. Submitted to prolonged meteoric influences (rain, frost, percolating water, etc.), it decomposes into a loose, crumbling mass, which is ultimately wasted away to form new combinations. Let us endeavour to trace the history of the three constituent minerals. First the quartz: this mineral, though chemically unaffected, becomes mechanically separated from its associates, and reduced by trituration to small partially rounded grains, in which condition it goes to form deposits of sand, and these when consolidated give rise to sandstone. Mixed with the quartz, one would naturally expect to meet occasionally with fragments of undecomposed felspar and mica; and such indeed is the case, as may be seen in certain felspathic and micaceous varieties of sandstone.

The felspar, on the other hand, decomposes: its alkalies are removed in solution as carbonates, and there remains behind a silicate of alumina known as kaolinite. It is this substance which in exceedingly minute particles forms the basis of clays, and imparts to them their impervious and plastic qualities.

Finally, the mica, or ferro-magnesian constituent, is first converted into talc or chlorite, and then undergoes

further decomposition, the products being removed in solution.

With regard to the dissolved portions, the alkalies (potash and soda) and alkaline earths (lime and magnesia) unite with materials derived from other sources to form chemical precipitates of various salts, *e.g.*, calcite, dolomite, magnesite, gypsum, rock-salt, etc.

Most of these minerals are included in our third division (p. 92); but a few notes on chlorite, talc, and serpentine are appended here.

Chlorite.—Monoclinic, but simulating hexagonal forms, occurring in six-sided plates and scales, sometimes giving rise to spherular and spiral aggregates. The basal cleavage is strongly pronounced. The separation, however, is not as perfect as in mica; nor are the flakes elastic. The hardness is, 1—1·5; specific gravity, 2·60—2·96; colour, green. Chemically chlorite is a hydrated silicate of magnesia, iron, and alumina. In one form or another is a very frequent alteration product, especially in the more basic igneous rocks. The green colour of many of the latter (greenstones) is due to the presence of this mineral.

Talc (steatite, soapstone)—is a hydrated silicate of magnesia ($H_2O, 3MgO, 4SiO_2$) crystallizing in the Rhombic system, but with pseudo-hexagonal symmetry. It is a pale green or colourless mineral, very soft, and with a greasy feel. Hardness, 1; specific gravity, 2·7—2·8. Cleavage, basal; flakes, non-elastic. Talc occurs as an alteration product of magnesian minerals in igneous and metamorphic rocks.

Serpentine—is a hydrated silicate of magnesia and iron: $2H_2O$, $3(MgFe)O$, $2SiO_2$. It is of a dull green colour, but is often stained yellow or red by the presence of iron oxides. Its hardness is 3—4; specific gravity, 2·5—2·7. It occurs massive, or in veins, as an alteration product of olivine and other ferro-magnesian minerals.

Kaolinite—is the chief constituent of kaolin or china clay, and probably of all clays. It is a hydrated silicate of alumina ($2H_2O, Al_2O_3, 2SiO_2$): crystallizing in the Rhombic system, but with pseudo-hexagonal symmetry. It occurs in minute colourless six-sided plates and scales. Hardness, 1—2; specific gravity, 2·34—2·57. Kaolinite is produced by the decomposition of felspar. Under the action of the weather this mineral loses its glassy character, becomes dull, and finally crumbles down into a white mealy powder, which consists principally of kaolinite. Kaolin mixed with quartz is, consequently, often found in the immediate neighbourhood of granite (see page 56).

Zeolites.—A group of hydrated silicates of various bases (alumina, potash, soda, lime, etc.), and crystallizing in different systems. They occur chiefly in the igneous rocks, especially in the basalts, filling cracks and cavities with their crystals and prismatic needles. They are all easily decomposed by hydrochloric acid with separation of gelatinous silica.

II. THE ORES AND VEINSTONES.

The ores are those minerals from which the metals are extracted. They consist of the oxides, sulphides, chlorides, carbonates, sulphates, etc., of the metals; and, in a few cases, of the native metals themselves (*e.g.*, gold, platinum, silver, and copper). Compared in bulk with the rock-forming minerals, they constitute an insignificant fraction of the earth's crust, occurring in its fissures and cavities, or disseminated in small particles or grains through its constituent rocks: only exceptionally do we meet with larger masses of ore that will in any way bear comparison with the rocks themselves (*e.g.*, certain iron-ores).

According to their mode of occurrence the ores may be arranged in three groups: (1) Those that are deposited during the accumulation of stratified formations; (2) those that are produced at the same time as the constituents of crystalline rocks; (3) those that are introduced subsequently into the fissures, pockets, and other cavities existing in rocks.

The ores embraced in the first group include: (*a*) The dust, grains, and nodules (nuggets) which are found mixed with ordinary sedimentary deposits, having been derived from earlier formations, *e.g.*, alluvial gold, stream-tin, iron-sand (fig. 62); (*b*) the ores deposited in beds, interstratified with other sedimentary rocks, and partaking of their geological structure, *e.g.*, certain ores of iron, such as limonite and siderite.

In the second group are embraced the ores that occur disseminated in minute particles through the igneous

rocks and crystalline schists, *e.g.*, magnetic iron-ore and iron-pyrites.

The third group is the most important, as it embraces the greatest number of the ores of economic importance. The chief forms in which the ores classed under this head occur are: (*a*), veins; (*b*), impregnations and stockworks; (*c*), chambers or pockets.

A **mineral vein** or **lode** is the result of the gradual infilling of a fissure by the successive deposition of mineral

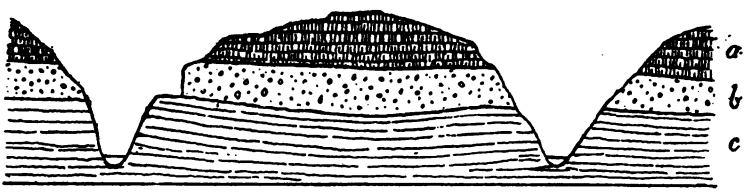


FIG. 62.—SECTION ILLUSTRATING THE OCCURRENCE OF ORE DEPOSITED DURING THE ACCUMULATION OF SEDIMENTARY MATERIAL.

a, capping of basalt. *b*, ancient river gravel, containing gold. *c*, solid rock, cut into by the river-valleys. (After J. A. Phillips.)

matter. The fissure is in some cases also a line of fault, as in fig. 64. The rock through which the vein passes is termed by miners the "country"; the boundaries of the vein are termed its "cheeks" or "walls." The material constituting the vein may consist of one, or of several minerals, and these again may consist entirely of ores, or of ores in association with non-metalliferous material (veinstone, vein-stuff, or gangue). Although occasionally the contents of the vein show no definite structure, the fact that they have been deposited in

regular layers is usually indicated by a banded structure, and in this case there is generally a symmetrical arrangement of the minerals (both ore and veinstone) towards the centre of the vein, so that the same succession of minerals is met with in passing from both walls towards the middle (see fig. 65).

Sometimes the ore, instead of having been introduced along sharply defined fissures, is disseminated in small

FIG. 63.—SECTION ILLUSTRATING THE OCCURRENCE OF ORES IN VEINS WHICH BOTH FOLLOW AND CUT ACROSS THE BEDDING. (After J. A. Phillips.)

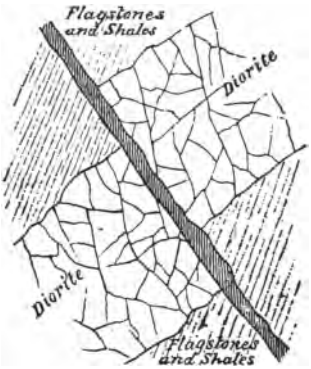


FIG. 64.—LODE FORMED BY DEPOSITION OF MINERALS ALONG A LINE OF FAULT. (After J. A. Phillips.)

particles through a particular portion of the rock. This kind of deposition is known as an **impregnation.** The impregnated area is usually found to be in connection with a lode or infilled fissure through which the impregnation may be assumed to have taken place (see fig. 66).

A **stockwork** is closely allied to an impregnation, but in

this deposit the ore, instead of being disseminated in particles, is distributed through the mass in a plexus of small interlacing veins.

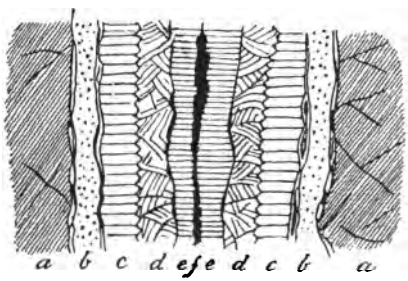


FIG. 65.—SECTION OF A MINERAL VEIN, Showing successive deposition of regular layers towards the centre of the vein. (After Geikie.)

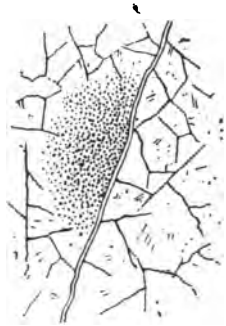


FIG. 66. — IMPREGNATION OF TIN-ORE AT EAST HUEL LOVELL. (After Phillips.)

Chambers or **pockets** are cavernous spaces in the rock

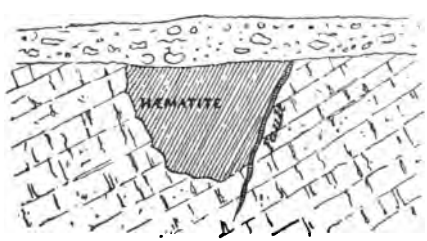


FIG. 67.—POCKET OF HÆMATITE IN CARBONIFEROUS LIMESTONE. (After Phillips.)

which have served as receptacles for the ore. Usually such pockets occur in limestone, which is a rock emi-

nently suited for the formation of the requisite cavities by reason of its solubility in water containing carbonic acid (see fig. 67).

The following pages are devoted to a description of the commoner ores of the metals, platinum, gold, silver, mercury, copper, iron, manganese, zinc, lead, tin, and antimony; and of some of the chief veinstones.

Platinum.

Platinum occurs native in small flattened grains and scales, but occasionally in larger nuggets. It crystallizes in the Regular system; but crystals are rare, only small cubes having been infrequently found. Its colour lies between a steel grey and a silver white. It takes a higher polish than silver. Its hardness is 4·5—5; specific gravity, 17—18, amounting in pure platinum to 21·5. Platinum is thus one of the heaviest metals known. It is rarely found pure, generally containing iron (5—13 per cent.) and small quantities of a group of allied rare elements, viz., iridium, rhodium, palladium, and osmium.

Loose grains of the metal, accompanied by gold, iridium, palladium, chrome iron-ore, magnetite, zircon, and corundum, occur in the drift-sands covering the slopes of the Ural Mountains. It has also been found in Borneo, Brazil, and California.

On account of its infusibility, and the difficulty with which it is attacked by acids, it constitutes an invaluable material for chemical vessels, crucibles, dishes, etc.

The Ores of Gold.

Gold occurs chiefly as **Native Gold**, other combinations, such as **Gold Amalgam** (a compound with mercury) or **Telluride of Gold** (a compound with tellurium), being rare.

Native gold crystallizes in the Regular system; but crystal forms (cube with octahedron) are rare, indistinct, and distorted. More usually it occurs in branched or wiry aggregates, in leaf-like expansions, or in minute grains disseminated through quartz. It is also found as dust, and in loose grains and nuggets. Large nuggets are occasionally found: thus one, weighing 161 lbs., was discovered in Upper California; and others have been found in Australia, one of which yielded 2,268 ounces of gold.

Gold is the most malleable of all metals. It is also soft, having a hardness of 2·5 to 3. Its colour varies from a reddish to a brassy yellow, the differences being caused by the presence of small and variable quantities of copper and silver. The amount of silver present in native gold varies from 1 to 40 per cent.; alloys with over 20 per cent. are termed *electrum*. The specific gravity of native gold ranges from 15·6 to 19·4, being less with increasing percentage silver. The specific gravity of pure gold is 19·37.

The metal is insoluble in all single acids, but dissolves readily in a mixture of nitric and hydrochloric acids.

Gold occurs (1) in place, mainly in quartz-veins (*reefs*), but also occasionally disseminated in minute specks through igneous rocks; (2) as transported material in the

screes and talus débris of mountain slopes (*drift-gold*), or in the sands of the rivers that drain them (*alluvial gold*). Transported gold is derived from the disintegration of the gold-bearing quartz which veins the old crystalline rocks of mountain districts. The metal is also found in the mudstones, sandstones, and conglo-

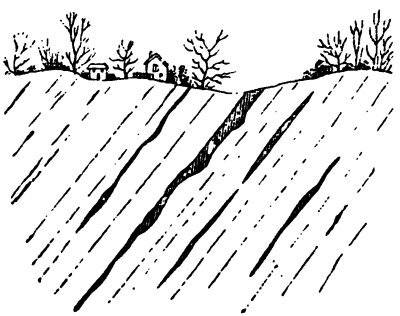


FIG. 68.—SECTION SHOWING VEINS OF AURIFEROUS QUARTZ FOLLOWING THE BEDDING. (After Phillips.)

merates (*banket*) that have been produced by the consolidation of auriferous mud, sand, and shingle.

Gold occurs in numerous localities throughout the world; but the most important gold-fields are situated in Australasia (Victoria, New Zealand, New South Wales, and Queensland), the United States (California, Nevada, and Colorado), South Africa (the Transvaal), and Russia (Ural Mts.).

Auriferous Pyrites. In the deeper-seated portions of the quartz reefs the gold is often found in intimate association with iron, copper, or arsenical pyrites; and it seems likely that a considerable proportion of the free gold is produced by the decomposition of these minerals.

The Ores of Silver.

Native Silver.—Regular. Native silver, when crystallized, presents cubical or octahedral forms, but the crystals are usually distorted or united to divergent branching masses. More frequently, however, the metal occurs in strings and wiry coils, occasionally even forming a moss-like aggregate; it is also found in the shape of plate or foil, or as amorphous lumps. One such mass from Kongsberg in Norway, which is preserved in the Copenhagen Museum, weighs about five tons.

Silver is very malleable and ductile, ranking next to gold in these qualities. In hardness it lies between gold and copper, its position in Mohs' scale varying from 2·5—3. The specific gravity of native silver ranges from 10·1 to 11·0: pure silver is 10·5. Although naturally of a white colour, it is often tarnished superficially to a red, brown, or blackish colour. The native ore contains traces of copper, arsenic, antimony, and iron. It is soluble in nitric acid, and gives a precipitate with hydrochloric acid.

Native silver occurs in veins, associated with the other ores of silver, or intermingled with native copper as at Lake Superior. The largest deposits are found in the mines of Peru and Mexico. In Europe it is found in Norway, the Hartz, Saxony, Hungary, and the Dauphiné.

The commonest *compounds of silver* occurring as ores are the sulphides either of silver alone, or of silver with copper, arsenic, antimony, iron, lead, etc. The richest and most abundant of these is **Argentite**, a sulphide of

silver (Ag_2S) crystallizing in the Regular system. It occurs in cubes, octahedra, and rhombic dodecahedra, but also massive. Its colour is a dull black or lead grey. It is very soft (hardness 2 to 2·5), and has a shining black streak. Its specific gravity is 7—7·4.

Argentite contains 87 per cent. of silver, the remainder being sulphur, which may be easily removed by heating on charcoal with the blowpipe, leaving a bead of the metal.

It is found in Saxony, Bohemia, and Hungary in Europe; in Mexico, and in the United States.

Another rich ore of silver is **Stephanite** or **Brittle Silver Ore**, a rhombic sulphide of silver and antimony. It occurs massive, or crystallized in thick six-sided tablets or short prisms.

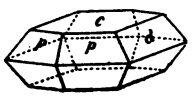


FIG. 69.—STEPHANITE.
c, basal plane.
p, pyramid.
d, brachy-dome.

This mineral has an iron-black colour, is soft (hardness, 2—2·5), and has a specific gravity of 6·2—6·3. Its chemical composition is represented by the formula $5Ag_2S + Sb_2S_3$, which gives a silver percentage of 68·36. Before the blowpipe on charcoal it yields a button of silver. Stephanite occurs in Saxony, Bohemia, Hungary, Chili, Peru, Mexico, and Nevada.

Next in importance to argentite and stephanite are the **Ruby Silver Ores.** These are of two kinds, differing in tint and composition, the darker (*pyragyrite*) being a sulphide of silver and antimony, the lighter (*proustite*), a sulphide of silver and arsenic. Both minerals crys-

tallize in the Hexagonal system, in isomorphous forms, namely, short columns terminated by the faces of a rhombohedron. Cleavage, rhombohedral; fracture, conchoidal.

Pyrargyrite has a dark cochineal red colour, which turns to black on exposure to light. Proustite is of a lighter red. Both minerals are characterized by an adamantine lustre, and have a hardness of 2; but pyrargyrite is heavier than proustite (Sp. G., 5·75—5·85, as compared with 5·5—5·6). The antimony ore contains 59·78 per cent. of silver; and the arsenic ore, 65·41 per cent. Before the blowpipe they both yield a globule of silver when fused with carbonate of soda on charcoal. These ores occur in Saxony, Hungary, the Hartz, Norway, Spain, Mexico, Nevada, and Chili.

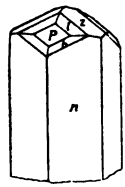


FIG. 70.—PYRARGYRITE.
P, rhombohedron (+*R*).
z, a more obtuse rhombohedron (−½ *R*).
h, a scalenohedron.
n, prism.

Other less important sulphides containing silver are **Polybasite** (sulphide of silver, copper, and arsenic), and **Freieslebenite** (sulphide of silver, lead, and antimony). Some varieties of **Tetrahedrite** (Fahlerz), which is an ore of copper, contain a considerable quantity of silver (10 to 30 per cent.). A large amount of silver is also obtained from a sulphide of lead, **Argentiferous Galena.** See *Galena*.

Besides the sulphur compounds, the haloid compounds of silver are important as ores, being especially abundant in Chili, Peru, Mexico and New South Wales. These

are the chloride (kerargyrite), chloro-bromide (embolite), and iodide of silver.

Kerargyrite or **Hornsilver** crystallizes in the Regular system, but usually occurs massive. It is of a white to whitish-grey colour, with a greasy lustre; extremely malleable and soft (hardness, 1); and has a specific gravity of 5·58—5·6. It is a very rich ore of silver, containing 75·3 per cent. of the metal, the remainder being chlorine. It is probably a product of alteration of other silver ores, as it appears to occur only in the upper part of argentiferous lodes.

The chloro-bromide of silver or **Embolite** occurs in small particles of a greenish colour. It contains 67 per cent. of silver, and has a specific gravity of 5·79 to 5·80.

The iodide is quite rare.

Mercury.

Cinnabar.—This is the only important ore of mercury. It is a sulphide of the metal.

Crystallizing in the Rhombohedral system, it sometimes occurs in thick tabular crystals, composed of the basal plane in combination with rhombohedral faces. More frequently, however, it is found massive.

Its colour is a bright crimson or cochineal red; its streak, scarlet. The crystals are pellucid, and have an adamantine lustre. The hardness is 2—2·5; specific gravity, 8—8·2. The chemical composition of cinnabar is represented by the formula HgS, or 86·2 per cent. of mercury, to 13·8 per cent. of sulphur. It occurs in veins or lodes, or disseminated in specks through sandstone; Spain, Peru, and California being the chief sources.

Copper Ores.

Native Copper.—Regular. When crystallized, this metal occurs in small and large crystals, having the forms of the octahedron, the cube, and the rhombic dodecahedron, all of which are usually much distorted, and aggregated to irregular branching masses. Most frequently, however, no crystalline form is visible, the metal occurring in irregular lumpy masses, in wiry and mossy coils, or as foil and in plates. Its colour is the familiar copper-red, but the surface is often tarnished, and then of a dirty yellow or brown colour. The metal is malleable, ductile, and tenacious. Its hardness is 2·5—3, and its specific gravity, 8·5 — 8·9. Chemically native copper is usually pure, but it sometimes contains traces of iron and silver.

FIG. 71.—NATIVE COPPER.
(From a photograph.)

Copper was one of the earliest known metals, and was much prized by the ancients on account of its toughness, being used by them in an alloy with one-tenth of its weight of tin for the manufacture of weapons and tools. The native metal is found in Cornwall, Siberia, Brazil, and at Lake Superior in the United States. One great mass, weighing 400 tons, was discovered at the last-named locality.

The principal ores of copper are its compounds with oxygen and sulphur. There are two oxides found in the native state, namely, cuprite and tenorite. The latter, however, is unimportant as an ore.

Cuprite or **Ruby Copper Ore.**—Regular, occurring in well formed octahedra, either alone, or in combination with the cube and the rhombic dodecahedron. It is also found massive and granular, or as a brick-red, earthy mass (*tile-ore*). It has a brilliant cochineal red colour, which is best seen in transparent crystals, or on reducing opaque specimens to powder; and possesses a lustre which is partly metallic, partly adamantine. Its hardness is 3·5—4; and its specific gravity, 5·7—6.

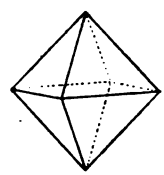


FIG. 72.—CUPRITE. Octahedron.

Chemically it consists of 88 per cent. of copper, combined with 12 per cent. of oxygen (Cu_2O). Before the blowpipe on charcoal it yields a metallic globule of copper. The ease with which it can be reduced, makes it one of the best ores for the extraction of the metal.

There are four important sulphur compounds of copper:

Copper-glance or **Redruthite** is a di-sulphide of copper, crystallizing in the Rhombic system. The crystals have a pseudo-hexagonal symmetry, being flat six-sided tablets, composed of pyramids and brachy-domes, or of prisms and brachy-pinacoids, terminated in both cases by the

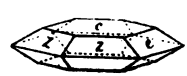


FIG. 73.—COPPER-GLANCE.
c, basal plane.
z, pyramid.
e, brachy-dome.

basal plane. The crystals are frequently twinned, the twinning plane being a face of the prism. More frequently, however, the ore is massive, platy, or nodular. It has a dull, black colour; is soft (hardness, 2·5—3); and has a specific gravity of 5·5—5·8.

This is a rich ore of copper, containing 79·85 per cent. of copper, the remainder being sulphur. It occurs in Cornwall, Saxony, Siberia, and other places.

Copper-pyrites or **Chalcopyrite.**—Tetragonal, the commonest form being the hemihedral sphenoid; but the crystals are usually small and distorted, and consequently are difficult to determine. They are often twinned, on various types.

FIG. 74.—BLISTER-COPPER.
A variety of copper-pyrites. (From a photograph.)

Mostly, however, it occurs massive, in large nodular, kidney-shaped, or botryoidal masses (*blister-copper*), and in scattered grains. It has a conchoidal to irregular fracture. Its colour is brassy to golden yellow, being a stronger yellow than that of iron-pyrites. The surface of the mineral is often iridescent in blue or red tints, which are the result of tarnish (*peacock-ore*).

Its streak is black. Hardness, 3·5—4; specific gravity, 4·1—4·3. It may be distinguished from iron-

pyrites by its lesser hardness, and from gold by its brittleness, crumbling under the point of the knife. Chemically it is a sulphide of copper and iron, containing 34·5 per cent. of copper, 30·54 per cent. of iron, and 39·89 per cent. of sulphur.

Copper pyrites is the most frequent of all copper ores, and the largest amount of the metal is extracted from it. Its sulphur is also utilized in the manufacture of oil of vitriol. It may be said to occur wherever other copper ores are found. The most important deposits in Europe are those of Cornwall, Saxony, the Hartz, Hungary, Sweden, Ural Mountains, and Spain (Rio Tinto).

Erubescite.—Other names are *bornite*, *purple ore*, *horse-flesh ore*, and *variegated copper ore*.

This mineral crystallizes in the Regular system, but is usually found in the compact form, occurring in nodular masses or in disseminated granules. It has a reddish brown to coppery colour, but its surface is usually tarnished, presenting then iridescent tints of blue, purple, and red. Its hardness is 3; specific gravity, 4·9—5·1; fracture, conchoidal. In composition it is a sulphide of copper and iron, represented by the formula $Cu_2S + CuS + FeS$, and containing 55·6 per cent. of copper. It is important as a source of copper, being found in Cornwall, Norway, Siberia, the Cape Colony; and in Chili, Peru, and Mexico.

Malachite—The green carbonate of copper, is also an important source of the metal. It is worked in South Australia, South Africa, and in the Ural Mts.

Iron Ores.

The ores of this important metal are abundant and widespread. Those in chief use for the manufacture of iron are the oxides,—*magnetite, hæmatite, limonite,* and the carbonate,—*spathic iron-ore.* The sulphides, although abundant and containing a large proportion of the metal, are not used for its production.

Magnetite, or **Magnetic Iron-ore.**—Crystallizes in the Regular system, occurring in very perfect octahedra or rhombic dodecahedra. More frequently, however, it is found in granular and compact masses; in minute particles, scattered through many igneous rocks and crystalline schists; or in loose rounded granules ("iron-sand") that have been washed out of igneous rocks. Its fracture is conchoidal to uneven. Hardness, 5·5—6·5; specific gravity, 4·9—5·2. It possesses an iron-black colour, black streak, and metallic lustre. Its magnetic properties are pronounced, and it was these qualities that caused it to be esteemed by the ancients under the name of the *loadstone.*

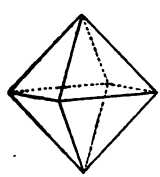


FIG. 75.—MAGNETITE. Octahedron.

Its composition is represented by the formula Fe_3O_4, and it may be regarded as a mixture of the protoxide, with the sesquioxide, of iron ($FeO + Fe_2O_3$). It is a rich ore, containing 72·41 per cent. of the metal, the remainder (27·59 per cent.) being oxygen. When powdered it is easily soluble in hydrochloric acid. Before the blowpipe it fuses only with difficulty.

This ore furnishes a large proportion of the iron produced in Norway, Sweden, Russia, and the United States; but comparatively very little is found in this country. It is associated with plutonic igneous rocks of basic composition, and appears to be connected with them in origin.

Hæmatite.—Hexagonal or rhombohedral. This iron-ore comprises two varieties: the *crystallized* or *specular iron-ore*, and the amorphous and earthy material known as *red hæmatite*.

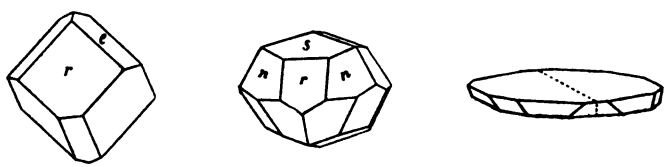


FIG. 76.—SOME COMMON FORMS OF HÆMATITE.

r, rhombohedron. *e*, a negative rhombohedron.
s, a more obtuse rhombohedron. *n*, a deutero-pyramid.

The crystals are partly of a rhombohedral and pyramidal habit, partly tabular, according as rhombohedral and pyramidal faces, or the basal plane predominates. The prismatic faces are always subordinate. The rhombohedral faces are often curved, passing gradually over into the basal plane. Specular iron ore derives its name from its brilliant metallic lustre (*speculum* = a mirror), dark steel colour, and a cherry red streak, distinguishing it from magnetite. Hardness, 5·5—6·5; specific gravity, 5·19—5·28. It also occurs in granular and scaly aggregates, this variety being known as *micaceous hæmatite*.

Chemically it consists of the sesquioxide of iron, Fe_2O_3, and contains 70 per cent. of iron combined with 30 per cent. of oxygen.

The ordinary red iron ore is not crystallized, its structure being either crypto-crystalline or earthy. It occurs in nodular and botryoidal masses, having a smooth exterior and a radiating internal structure (*kidney-ore*); and it also forms stalactitic aggregates. The earthy variety

FIG. 77.—KIDNEY IRON-ORE.

A variety of hæmatite. (From a photograph.)

is termed *red ochre*, and is used as a paint. "Kidney-ore" is found chiefly in the Carboniferous Limestone. Hæmatite is an important source of iron in this country. Small quantities are found in Cornwall, Devon, and South Wales; but a large quantity is raised in North Lancashire and Cumberland; and is imported from Spain. The crystallized variety (specular iron) is derived chiefly from Elba, St. Gothard, and Brazil. It is also found as an incrustation on lava at Vesuvius.

Limonite, or **Brown Iron-ore.**—This, the hydrated oxide of iron, is one of the commonest ores of the metal. It does not form definite crystals, having a crypto-crystalline to earthy structure. It occurs in nodular, botryoidal, kidney-shaped, or stalactitic masses, frequently having an internal fibrous structure. It also forms concretionary grains, constituting the so-called *pisolitic* or *oolitic iron-ore*. In colour it varies from yellow to blackish brown. It is opaque, with a dull lustre, and has a yellowish brown streak. Its hardness is 5—5·5; specific gravity, 3·4—3·95.

The chemical constitution of limonite is expressed by the formula $2Fe_2O_3 + 3H_2O$, which is equivalent to 85·56 per cent. of oxide of iron (iron 60 per cent.), and 14·44 per cent. of water. Under this head may be classed the granular lake-ores of Sweden, which are deposited at the bottom of lakes; also bog-ore, which is found as a compact layer (*pan*) under marshes and wet moor-land.

Limonite is an important iron ore on account of its abundance and wide distribution. The pigments, known as ochres and umbers, are chiefly prepared from certain earthy varieties of this mineral by calcining at different temperatures.

Spathic or **Sparry Iron-ore.**—Also known as *siderite* and *chalybite*. This mineral crystallizes in the Hexagonal system, usually in flat rhombohedra with curved faces. It also occurs massive or mixed with clay (*clay ironstone*). Cleavage, rhombohedral. Hardness, 3·5—4·5; specific gravity, 3·7—3·9. Colour, buff or fawn.

Spathic iron-ore is a carbonate of iron ($FeCO_3$), con-

taining 62 per cent. of ferrous oxide (48·2, iron) and 37·93 of carbon dioxide. It often contains carbonates of lime, magnesia, and manganese. Soluble in acids with effervescence of carbon dioxide.

The nodules of clay ironstone, which are found in the shales of the Coal Measures, are termed *sphærosiderite*. This variety of the ore forms the staple material of the British iron production. The varieties used in smelting contain from 25—35 per cent. of iron. The *blackband ironstone* is an impure carbonate of iron interstratified as a thin band in the Coal Measures: it is valuable on

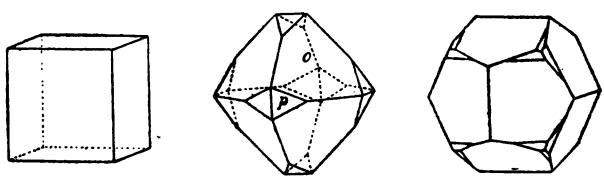


FIG. 78.—CRYSTALS OF IRON-PYRITES.

account of its containing sufficient coaly matter to calcine it.

Iron-pyrites. — Crystallizes in the Regular system. The cube, either alone or combined with the faces of the pentagonal dodecahedron and the octahedron, is the most frequent form. The faces of the cube are usually striated in consequence of an oscillatory combination with the pentagonal dodecahedron. The latter form also occurs alone, the striation of the faces alone indicating the influence of the cube.

The crystals are of all sizes, and occur either singly or grouped. Iron-pyrites also occurs in nodular, botry-

oidal, kidney-shaped forms, but most frequently in compact masses: also in scattered grains, diffused through numerous igneous and sedimentary rocks. Its colour is brassy yellow, but the surface is frequently tarnished; and the mineral alters easily into a dark brown variety of limonite, the change being one of hydration. Pyrites has a brownish black streak. The fracture is conchoidal to uneven. A cleavage is scarcely perceptible. Hardness, 6—6·5; specific gravity, 4·9—5·2. Its hardness is important as it distinguishes it from copper-pyrites and from gold.

Iron-pyrites is a sulphide of iron (FeS_2) containing 46·67 per cent. of iron and 53·33 per cent. of sulphur.

Marcasite or **Rhombic Pyrites** is a mineral of the same composition, but crystallizing in the Rhombic system. Its curious form has caused it to be also designated "Cockscomb-pyrites." These two minerals are very widely diffused through the crust of the earth; but, although they contain a high percentage of iron, they are not used for the production of that metal. The chief use of pyrites is for the manufacture of oil of vitriol, for which purpose it is imported from Spain, Portugal, and Belgium, besides being largely found in our own metalliferous mines. Pyrites often contains gold (*auriferous pyrites*), and when the noble metal is present in remunerative proportions the ore is treated for its extraction.

Another sulphide of iron is **Pyrrhotine** or **Magnetic Pyrites.** Although crystallizing in the Hexagonal system, this mineral is mostly found massive. It has a bronzy colour, and is slightly magnetic. Its hardness is 3·5—

4·5; specific gravity, 4·54—4·64. Its composition varies from Fe_6S_7 to $Fe_{11}S_{12}$, corresponding to iron, 60—61 per cent., sulphur, 40—38·4 per cent.

Pyrrhotine is used with iron-pyrites for the manufacture of oil of vitriol.

Nickeliferous Pyrites is a variety of magnetic pyrites containing nickel. It is found in Sweden and Canada, and is raised for the production of nickel. A great amount of nickel, however, is now obtained from the New Caledonian ore (*Garnierite*) which consists of nickel oxide associated with a green magnesian silicate.

Manganese Ores.

The chief ore of manganese is **Pyrolusite**, which crystallizes in the Rhombic system, but is mostly found in earthy masses, or in botryoidal, kidney-shaped and nodular aggregates, possessing an internal radiating fibrous structure. In colour it is black and opaque, with dull, but sometimes silky, lustre. Its streak is black, soiling the fingers. Hardness, 2·25; specific gravity, 4·7—5. The chemical composition of pyrolusite is represented by the formula MnO_2, *i.e.*, it consists of 63·22 per cent. of manganese, and 36·78 per cent. of oxygen. This mineral is used for many purposes, *e.g.*, in preparation of oxygen in the manufacture of chlorine for bleaching powder, for the decoloration of glass, as a pigment, etc.

Chief among the other ores of manganese are **Manganite**, which is a black hydrated oxide of manganese ($MnO_2 + H_2O$), crystallizing in the Rhombic system; **Wad**,

another hydrated oxide, occurring in nodular botryoidal and earthy aggregates of a brown black colour; and **Manganese Spar**, a pink carbonate of manganese, crystallizing in the Rhombohedral system. The last-named mineral is found near Freiberg in Saxony, in Hungary, and other European localities. It also forms an important source of manganese in North Wales at the present time.

Zinc Ores.

Although there are several minerals which contain zinc, only four ores are of commercial importance, namely, for the extraction of the metal. These are the sulphide, the carbonate, and the hydrous and anhydrous silicates of zinc.

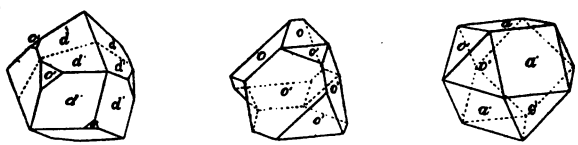


FIG. 79.—TWINNED CRYSTALS OF BLENDE.

o, octahedron. *a*, cube. *d*, rhombic dodecahedron.

Zinc Blende.—Sulphide of zinc crystallizing in the Regular system, but mostly found massive, or in granular, nodular, and botryoidal aggregates. The crystals are twinned in complicated types. Though occasionally colourless, it is usually of some shade of yellow, brown, or black. The light-coloured varieties are transparent to translucent. The lustre is high, and

of a resinous or adamantine character. The mineral is further characterized by a very perfect dodecahedral cleavage. Its specific gravity is 3·9—4; its hardness, 3·5—4. Streak, white to yellow. Its chemical composition is represented by the formula ZnS, or zinc, 67 per cent., and sulphur, 33 per cent.

Blende is found abundantly abroad, in numerous localities. The black variety, "Black Jack," is found in this country in Cornwall, Derbyshire, Cumberland and Isle of Man.

Calamine or Zinc-spar.—Carbonate of zinc, crystallizing in the Rhombohedral system, being isomorphous with calcite. When crystallized, it occurs in small crystals with curved faces. Usually, however, it is found in kidney-shaped and botryoidal aggregates, or massive. Its cleavage is rhombohedral. Though most often colourless, it is sometimes tinted grey, yellow, brown, or green, with vitreous or pearly lustre. Specific gravity, 4·1 to 4·5; hardness, 5.

Its chemical composition is represented by the symbol ZnS, which is equivalent to 64·8 per cent. of zinc oxide, and 55·2 per cent. of carbon dioxide. The carbon dioxide is driven off with effervescence on the application of an acid. Calamine is found in Cumberland, Derbyshire, and many places in Europe (Greece, Hungary, Silesia, Belgium, etc.), and in the United States of America.

Hemimorphite.—Hydrated silicate of zinc. Crystallizes in the Rhombic system, with hemimorphic development of the crystals *i.e.*, the crystals present different combinations of forms at the two ends of the vertical axis (hence

its name). The crystals are usually small tablets, which are combined to fan-shaped, spherical, and kidney-shaped aggregates. It also occurs in fibrous and granular masses. Prismatic cleavage. Although often colourless or white, it is also grey, yellow, brown, or even of a green or blue tint. The crystals are usually transparent, and have a glassy lustre.

The specific gravity of hemimorphite is 3·35—3·50; its hardness, 5. Its chemical composition is $ZnSiO_4 + H_2O$, which is equivalent to 67·5 per cent. of oxide of

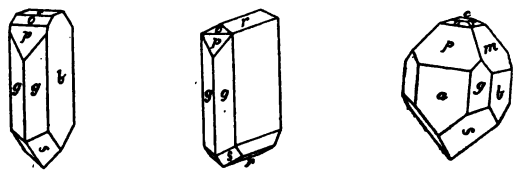


FIG. 80.—CRYSTALS OF HEMIMORPHITE.

c, basal plane.	*g*, prism.
b, brachy-pinacoid.	*o* and *p*, macro-domes.
a, macro-pinacoid.	*m*, brachy-dome.

zinc, 25 of silica, and 7·5 of water. It is often associated with the carbonate of zinc, with which it was for some time confounded. It occurs in Hungary, Aix-la-Chapelle, Carinthia, etc.; and is esteemed as a valuable ore.

Willemite.—This is the anhydrous silicate of zinc. It is rhombohedral, occurring in small crystals. But usually it is found massive, granular, or in kidney-shaped aggregates. Colour, white, yellow, or brown. Specific gravity, 3·9—4·2; hardness, 5·5. Chemical composition, $ZnSiO_4$, corresponding to 72·97 per cent. of oxide of zinc, and 27·03 per cent. of silica.

In Europe it occurs near Aix-la-Chapelle, and in Carinthia and Servia, but it is only found in large quantities in New Jersey, U.S., where it is worked as a valuable ore of zinc.

Lead Ores.

The most important ores of lead are the sulphide (galena), and the carbonate (cerussite).

Galena—crystallizes in the Regular system, usually as

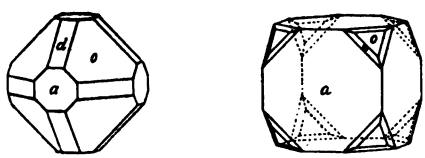


FIG. 81.—GALENA.

a, cube. *d*, rhombic dodecahedron.
o, octahedron. *e*, icosi-tetrahedron.

a combination of cube and octahedron. It also occurs massive, and in grains. It possesses a well-developed, cubical cleavage, a hardness of 2·5, and a specific gravity of 7·3—7·6. Its colour is lead-grey, with bright metallic lustre, but the mineral tarnishes on exposure to air.

The chemical composition of galena is represented by the formula PbS, which is equivalent to 86·6 per cent. of lead, and 13·4 per cent. of sulphur. Generally a small proportion of silver is present. In *argentiferous galena* enough silver is present to make the mineral a valuable source of that metal.

Galena is often associated with ores of copper and zinc. It occurs in the west of England in clay-slate, and in the north of England in the Carboniferous Limestone. It also occurs extensively in France, Germany, Spain, Belgium, and the United States of America.

Cerussite—crystallizes in the Rhombic system, being isomorphous with aragonite. The crystals are partly of a pyramidal habit, partly tabular, and are often twinned

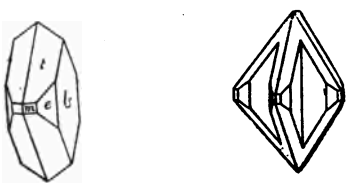


FIG. 82.—SIMPLE AND TWINNED CRYSTALS OF CERUSSITE.

t, pyramid. *e*, brachy-prism.
m, prism. *b*, brachy-pinacoid.

on faces of the prism. They are usually colourless and pellucid; but less transparent and white, or slightly tinted, varieties occur, occasionally forming delicate silky and fibrous aggregates. The crystals are characterized by a brilliant, adamantine lustre. Hardness, 3—3·5; specific gravity, 6·4—6·6.

Cerussite is a carbonate of lead, having the composition, $PbCO_3$, and containing 83·52 per cent. of lead. It is a valuable ore of lead, and occurs in Cornwall, Derbyshire, and Scotland (Leadhills), also in Spain and in the United States.

Tin Ore.

The only ore from which tin is produced is the binoxide.

Cassiterite or **Tinstone**—crystallizes in the Tetragonal system, the common form being the pyramid, combined with the prism of the same order. The edges of both pyramid and prism are, however, sometimes truncated

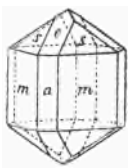


FIG. 83.—TINSTONE.
s, proto-pyramid.
m, proto-prism.
e, deutero-pyramid.
a, deutero-prism.

FIG. 84.—NODULES OF TINSTONE (STREAM-TIN). (From a photograph.)

by the faces of the pyramid and prism of the second order. The faces of the first pyramid show a horizontal, those of the prism a vertical striation. The crystals are often twinned. Tinstone also occurs massive in fibrous nodules (*wood-tin*) in grains dispersed through granite, but most frequently in loose rounded fragments, mingled with the sandy deposits of rivers (*stream-tin*).

The hardness of cassiterite ranges from 6 to 7; its specific gravity from 6·8 to 7. Its colour is usually brown or black, but yellow and grey tints also occur. A well-marked characteristic is the greasy to adamantine lustre.

Cassiterite is the binoxide of tin, represented by the formula SnO_2, and containing when pure 78·6 per cent. of tin, and 21·4 per cent. of oxygen.

The chief source of this ore was formerly in Cornwall, but a considerable quantity is now derived from the East Indies and from Australia (Queensland, New South Wales, and Tasmania).

Antimony Ore.

The only useful ore of antimony is the sulphide.

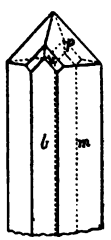


FIG. 85.—ANTIMONITE. *p*, pyramid. *m*, prism. *b*, macro-pinacoid.

Antimonite, Stibnite, or Antimony Glance—crystallizes in the Rhombic system, occurring in divergent aggregates of long prismatic or acicular crystals, with pyramidal terminations. The crystals are characterized by a well-developed pinacoidal cleavage. The colour is leaden grey with a bright metallic lustre, which is especially evident on the cleavage faces. Specific gravity, 4·6—4·7; hardness, 2. The chemical composition of antimonite is represented by Sb_2S_3, which is equivalent to 71·76 per cent. of antimony and 28·24 of sulphur.

The principal sources of the ore are at present Australia, Borneo, and Japan; but formerly it was largely obtained from European sources, namely, Hungary, the Hartz, France, and Spain.

Veinstones or Gangue-material.

In constant association with the ores in the lodes and veins are a number of minerals known as veinstones or gangue, which usually are of no commercial value, but possess a scientific interest in consequence of the constant association of certain of them with some of the important ores. Thus gold when found *in situ* is universally associated with quartz, this mineral in this case constituting its gangue or veinstone.

Among the commoner veinstones are the minerals quartz, calcite, dolomite, and fluor-spar. Of these quartz has already been described among the rock-forming minerals.

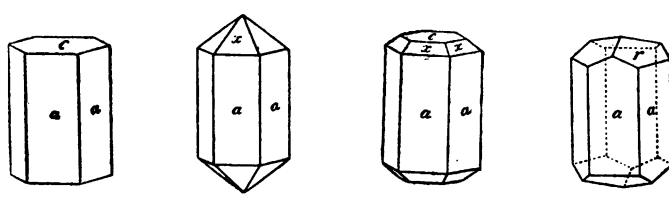


FIG. 86.—CALCITE: PRISMATIC FORMS.

c, basal plane. *x*, pyramid. *r*, rhombohedron. *a*, prism.

Calcite—is a carbonate of lime crystallizing in the Rhombohedral system, and characterized by the great variety of its crystal-forms. It occurs, for instance, in flat or acute rhombohedra; in sharp-pointed scalenohedra (*Dog-tooth Spar*), or in prismatic crystals, terminated by the basal plane. The purest variety is colourless and transparent (*Iceland-spar*), but other varieties are opaque and white, or stained yellow, red, and brown

by the presence of impurities. Its specific gravity is 2·72; its hardness, 3. The cleavage, which is parallel to the rhombohedron, is very perfect. This mineral

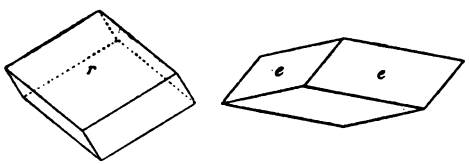


FIG. 87.—CALCITE: RHOMBOHEDRAL FORMS.
r, rhombohedron (R).
e, a more obtuse rhombohedron($-\frac{1}{2}$ R).

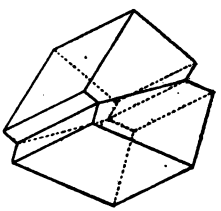


FIG. 88.—CALCITE: twinned crystal. (Twin-plane, a face of the rhombohedron $-\frac{1}{2}$R.)

effervesces with acids in the cold, carbon dioxide being eliminated; its chemical composition is represented by

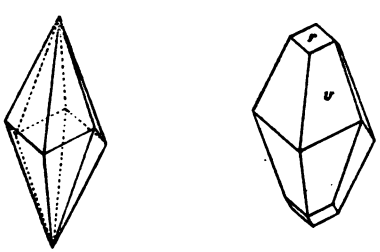


FIG. 89.—CALCITE: SCALENOHEDRAL FORMS.
v, scalenohedron (R^3).

the formula $CaCO_3$, with 56 per cent. of lime, and 44 per cent. of carbon dioxide. Besides its occurrence as veinstone, it is found massive as marble.

Carbonate of lime also crystallizes in another system, namely, as **Aragonite**, a rhombic mineral, which also occasionally occurs as a veinstone. This mineral is found in six-sided prisms and needles, which often unite to fibrous aggregates. Its specific gravity is 2·9—3; its hardness, 3·5—4.

Dolomite or **Pearl-spar**—is a carbonate of lime and mag-

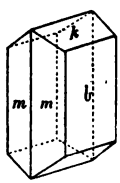


FIG. 90.—ARAGONITE.

b, brachy-pinacoid.
m, prism.
k, brachy-dome.

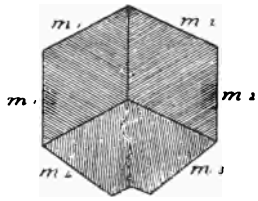


FIG. 91.—DIAGRAM

Illustrating the mode of twinning in Aragonite: 4 individuals twinned on a face of the prism. The striation indicates the direction of the brachy-diagonal.

nesia. It is isomorphous with calcite, which it much resembles. In consequence of this isomorphism, dolomite contains variable proportions of the two carbonates. This mineral is also associated with certain ore-deposits.

Fluor-spar—crystallizes in the Regular system, occurring in cubes and octahedra, usually in combination with the rhombic dodecahedron and icositetrahedron. The crystals are transparent, and have a glassy lustre. In colour they range through shades of blue, violet-green,

and yellow. Cleavage, octahedral; specific gravity, 3·1—3·2; hardness, 4. Fluor-spar is a fluoride of calcium,

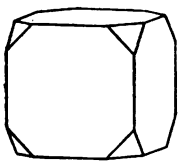


FIG. 92.—FLUOR-SPAR.
Cube with octahedron.

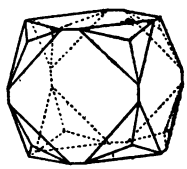


FIG. 93.—FLUOR-SPAR.
Cube with icositetrahedron.

(CaF_2), with 48·72 per cent. of fluorine and 51·28 per cent. of calcium. It is remarkable for its phosphorescence when heated.

As a veinstone, fluor-spar is associated with tin-ore in Saxony, Bohemia and Cornwall, with lead ores in Derbyshire, Cumberland and Northumberland, and with silver ores in Saxony, the Hartz and Norway (Kongsberg). The more beautiful varieties of the spar ("Blue John") are used for the manufacture of ornamental vases; while the commoner varieties are used as a flux in metallurgical processes, and for the preparation of fluoric acid.

III. THE SALTS.

Although every combination of an acid with a base may be termed a salt, we include here, for the sake of convenience, only the chlorides, sulphates, nitrates, borates, carbonates, and phosphates of the alkalies and alkaline earths. The compounds formed by the union of some of these acids with the heavier metallic bases have been already referred to among the ores.

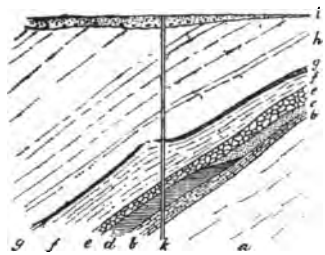


FIG. 94.—MODE OF OCCURRENCE OF SALT.

The Stassfurt deposits.

a, rock-salt.	*e*, kainite.	*f*, anhydrite.
b, kieserite.	*d*, carnallite.	*g*, gypsum.

These substances occur very frequently as beds that have been deposited from the waters of a former lake or inland sea; but many of them are found also as veins, which are thus the repository of mineral matter once carried in solution by percolating waters. Nitrates, on the other hand, are formed by the decomposition of organic matter in saliferous and rainless districts; while phosphatic deposits have in part been produced by the accu-

mulation of bones or of the coprolites of fishes. The sulphuric acid of the sulphates has been supplied in most cases by the decomposition of pyrites.

Chlorides, etc.

The most important chloride is **Rock-salt** or "**Salt.**" This mineral crystallizes in the Regular system, usually in cubes; but it also occurs massive. It has a perfect cleavage parallel to the faces of the cube. When pure it is colourless or white, but it is often tinted yellow, red, blue, etc., by the presence of a small quantity of some impurity. It is soluble in water and is easily recognizable by its saline taste. Its specific gravity is 2·1—2·2; hardness, 2—2·5. Its chemical composition is represented by the formula NaCl, which corresponds to 39·3 per cent. of sodium and 60·7 per cent. of chlorine. Rock-salt is found abundantly together with gypsum in the Permian and Triassic formations. In this country it is largely obtained from deposits of these formations in Cheshire, Gloucestershire and Staffordshire. Abroad it is found effloresing at the surface of the ground of rainless districts, *e.g.*, in Chili and the deserts of Africa. It also occurs as a product of sublimation in volcanic rocks, and a large quantity is contained in sea-water.

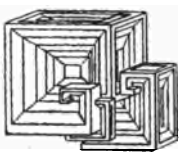


FIG. 95.—ROCK-SALT. Skeleton-cubes.

Sylvine—is the corresponding chloride of potassium. It crystallizes in the Cubic system. Colourless or white. Specific gravity, 1·9—2; hardness, 2. Chemical com-

position represented by the formula KCl. This gives potassium, 52·5 per cent.; Cl, 47·5 per cent. Easily soluble in water. Found at Stassfurt in Prussia, in association with sodium chloride and other salts.

Sal-ammoniac—is a chloride of ammonium crystallizing in the Regular system. Usually it occurs in stalactitic aggregation, or as an incrustation. When pure, it is colourless or white; but is often stained yellow by the presence of chloride of iron. Specific gravity, 1·52; hardness, 1·5—2. Its chemical composition is represented by the formula NH_4Cl, *i.e.*, it contains 66·26 per cent. of chlorine; 26·25 per cent. of nitrogen; and 7·49 per cent. of hydrogen. It is soluble in water and has a pungent saline taste. It occurs as an incrustation on lava at Vesuvius, Etna, and in other volcanic districts.

Carnallite—is a rhombic chloride of magnesium and potash. It is a white salt which is soluble in water and deliquesces when exposed to the air. Its chemical composition is $KMgCl_3+6H_2O$: or KCl, 26·8 per cent.; MgCl, 34·2 per cent.; and H_2O, 39 per cent. Found at Stassfurt in Prussia.

Cryolite—is a fluoride of sodium and aluminium, crystallizing in the Monoclinic system. It forms tabular crystals, or occurs massive. Colourless to greyish-white or yellow. Specific gravity, 2·95—2·97; hardness, 2·5—3. Chemical composition, $6\,NaF+Al_2F_6$; or aluminium, 12·85 per cent., sodium, 32·79 per cent., and fluorine, 54·36 per cent.

It is found in Greenland, and is raised chiefly for the preparation of the metal aluminium.

Borates.

Tinkal or **Borax**—is an acid borate of sodium, crystallizing in the Monoclinic system. This salt is colourless when pure, but usually contains foreign substances, which impart to it a yellow, green, or grey tint. It has a greasy lustre and is translucent. It dissolves in water, giving it a sweetish alkaline taste. Specific gravity, 1·74; hardness, 2—2·5. Its composition is represented by the formula $Na_2B_4O_7 + 10\ H_2O$, with 12·26 per cent. of soda, 36·59 per cent. of boracic acid, and 47·15 per cent. of water. It is found on the shores of lakes in Thibet, and in California and Nevada.

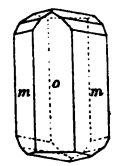


FIG. 96.—TINKAL.
o, ortho-pinacoid.
m, prism.

Boracite—is a chloro-borate of magnesia, crystallizing apparently in the Regular system, with tetrahedral development. According to recent view, the crystals are considered to be compound twins of rhombic or monoclinic individuals. The crystals are white, and usually semi-transparent. They have a vitreous lustre, a hardness of 7, and a specific gravity of 2·9 to 3. The chemical composition of boracite is represented by the formula $Mg_6B_{16}O_{30}, MgCl_2$, corresponding to 26·9 per cent. of magnesia, 62·5 per cent. of boracic acid, and 10·6 per cent. of chloride of magne-

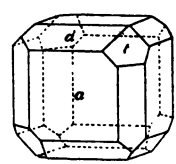


FIG. 97.—BORACITE.
a, cube.
d, rhombic dodecahedron.
t, tetrahedron.

sium. It is found inclosed in gypsum and anhydrite at Lüneburg and Segeberg, and in carnallite at Stassfurt in Germany.

Nitrates.

The important nitrates occurring as natural salts are those of the alkalies, potash and soda. They are used in the manufacture of nitric acid and of gunpowder; and as artificial manures they are also of great value.

Nitre, or **Saltpetre** (*Nitrate of Potash*)—crystallizes in the Rhombic system. It occurs in silky needle-shaped prisms or as an incrustation. Colourless, white or grey. Hardness, 2; specific gravity, 1·9—2·1. Easily soluble in water. Like all potash salts, nitre imparts a violet colouration to the flame of a spirit-lamp or Bunsen burner. Its chemical composition is represented by the formula KNO_3; or potash, 46·58 per cent., and nitric acid, 53·42 per cent. It is found as an efflorescent crust, or mixed with the soil of certain rainless districts, in Spain, Algeria, India, Quito; and is used principally for the preparation of gunpowder.

Soda-nitre, or **Chili Saltpetre** (*Nitrate of Soda*)—crystallizes in the Rhombohedral system, but is usually found as an efflorescent incrustation. Colourless, but also white or grey. Hardness, 1·5—2; specific gravity, 2·1—2·2. Deliquescent and easily soluble in water. Chemical composition, $NaNO_3$; or soda, 36·49 per cent. and nitric acid, 63·51 per cent. In common with all soda-salts it

colours the flame yellow. It is found mixed with clay and sand on the pampas of Chili and Peru. It is used for the preparation of nitric acid and as a manure, being too deliquescent for the manufacture of gunpowder.

Carbonates.

A great number of carbonates occur as natural salts. Some of them, namely, the carbonates of the heavy metals, have been mentioned among the ores; while others, such as calcite, aragonite, and dolomite, have been treated with the sparry veinstones.

Magnesite (*Bitterspar, Carbonate of Magnesia*)—crystallizes in the Rhombohedral system, being isomorphous with calcite. More usually, however, it occurs massive, in granular, fibrous, or compact aggregates. Colourless, white or yellow. Transparent to opaque. Hardness, 4—4·5; specific gravity, 2·9—3. Soluble in acids with effervescence, when in the state of powder and warmed. Chemical composition, $MgCO_3$; or magnesia, 47·62 per cent., and carbon dioxide, 52·30 per cent. It is found in several localities in Europe, in the United States and in Venezuela, being raised for the manufacture of Epsom Salts and sulphate of magnesia.

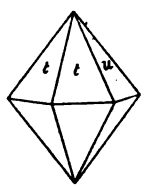


FIG. 98.—WITHERITE.
Pseudo-hexagonal pyramid composed of—
t, pyramid.
u, brachy-dome.

Witherite (*Carbonate of Barium*).—Rhombic, being

isomorphous with aragonite. Its compound forms closely resemble hexagonal pyramids. Also found massive or in botryoidal or kidney-shaped aggregates. Colour, white, grey or yellowish grey. Hardness, 3—3·5; specific gravity, 4·2—4·3. Chemical composition, $BaCO_3$; or baryta, 77·68, and carbon dioxide, 22·32. Colours the flame green. In this country it is found chiefly in Northumberland.

Stronianite—is the corresponding carbonate of strontium. It crystallizes in the Rhombic system, being isomorphous with witherite and aragonite. Colourless, but often grey, yellow or green. Hardness, 3·5; specific gravity, 3 6—3·8. Chemical composition, $SrCO_3$; or strontia, 76·17, and carbon dioxide, 29·83. Colours the flame red. It was first found at Strontian in Scotland, and is used in the purification of sugar.

Two carbonates of soda occur native, namely **Soda** and **Trona**, neither of which is of much importance. Soda is the normal salt, Na_2CO_3, crystallizing with 10 molecules of water. Trona is the acid carbonate, $2NaCO_3 + CO_2 + 4H_2O$. Both are found as white or grey earthy incrustations, but only in small quantities.

Sulphates.

Several important sulphates occur as natural salts. Of these the sulphates of the heavy metals have been referred to among the ores: but the sulphates of the alkalies and alkaline earths are treated here.

There are two sulphates of lime, both of which occur

at times in sufficiently large quantities to be regarded as bedded rocks.

Anhydrite—is the anhydrous sulphate of lime. It crystallizes in the Rhombic system, forming thick tabular crystals; but more often it is found massive in coarsely crystalline aggregates resembling marble in appearance. Colourless, white, or bluish white. Transparent to opaque. Hardness, 3—3·5; specific gravity, 2·8—3.

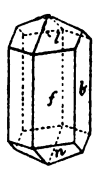


FIG. 99.—GYPSUM.

l, negative hemi-pyramid.
n, positive hemi-pyramid.
f, prism.
b, clino-pinacoid.

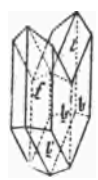


FIG. 100.—GYPSUM.

Crystal twinned on the ortho-pinacoid.

Anhydrite is characterized by a perfect pinacoidal cleavage. Its chemical composition is $CaSO_4$; or lime, 41·16 per cent. and sulphuric acid, 58·84 per cent. Occurs in beds associated with gypsum and rock-salt, especially in the red marl of the Permian formation.

Gypsum—crystallizes in the Monoclinic system, usually forming stout thick or long slender prisms, but occasionally occurring in flat rhomboid tablets. The tabular form is due to the predominance of the clino-pinacoid. Occasionally the crystals are lenticular with

curved faces. The crystals are either isolated or united to groups. Twinning on the ortho-pinacoid is common, producing a swallow-tailed form. The name *selenite* is applied to the crystallized variety. *Satin-spar* is a finely fibrous variety, having the appearance of satin, while the compact marble-like granular aggregate is known as *alabaster*. A very perfect cleavage exists parallel to the clino-pinacoid; and the cleavage faces show a pearly lustre. Hardness, 1·5—2; specific gravity, 2·2—2·4. Usually colourless and water-clear, but also white or tinted.

Gypsum is a hydrated sulphate of lime represented by the formula $CaSO_4 + 2H_2O$; or lime, 32·50, sulphuric acid, 46·51, and water, 20·95. It is a very common mineral occurring in beds and veins in marls and clays in the New Red Marl, Oxford Clay, Purbeck Beds, Gault, London Clay, etc. It is used in agriculture to improve soils, or is heated to make plaster of Paris. The compact granular variety (*alabaster*) is used for vases, statuary, etc.

Barytes or **Heavy-Spar.**—Rhombic: in numerous forms producing various types of prismatic and tabular crystals. Also compact, granular, fibrous, etc. Very perfect brachy-pinacoidal cleavage. Another perfect separation exists in the direction of the macro-dome. Hardness, 3·35; specific gravity, 4·3—4·7. The great weight of this mineral is one of its most striking characteristics. Colourless and water-clear, but also reddish-white, grey, or yellow. Vitreous lustre.

Barytes is a sulphate of barium, $BaSO_4$; or baryta, 65·7 per cent., and sulphuric acid, 34·3 per cent. It is

a very common mineral, being often associated with ores as a veinstone, or occurring alone in veins. It is principally raised for admixture with white lead.

Celestine—is the corresponding sulphate of strontium. Rhombic, being isomorphous with barytes. The crystal forms are similar to those described. Hardness, 3—3·5; specific gravity, 3·9—4. Colourless and water-clear, or

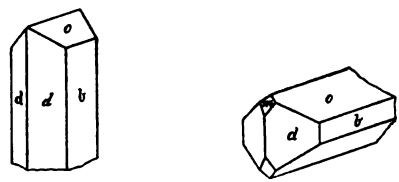


FIG. 101.—BARYTES.

b, brachy-pinacoid. *m*, macro-dome.
o, brachy-dome. *d*, prism.

bluish-white to grey. Chemical composition, $SrSO_4$; or strontia, 56·52 per cent., and sulphuric acid, 43·48. It is used for the preparation of strontium salts, and hence for the production of "red fire" in pyrotechnic displays.

Glauber's Salt. (Sulphate of Soda.)—Monoclinic; but occurs in nature mostly in the form of an efflorescence on rocks and old walls. It is colourless and easily soluble in water. Its hardness is 1·5—2; specific gravity, 1·4—1·5. Its chemical composition is $Na_2SO_4 + 10H_2O$; or soda, 19·3, sulphuric acid, 24·8, and water, 55·9.

Epsom Salts (Sulphate of Magnesia).—Rhombic; but occurs in nature as a powdery efflorescence. It is a

colourless salt, easily soluble in water, to which it imparts a bitter taste. Hardness, 2—2·5; specific gravity, 1·7—1·8. Its chemical composition is represented by the formula $MgSO_4 + 7H_2O$; or magnesia, 16·26 per cent., sulphuric acid, 32·52, and water, 51·22. It occurs on the steppes of Siberia, and in Catalonia. It also exists in solution, as in the springs at Epsom.

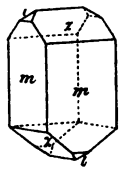


FIG. 102.—ARTIFICIAL CRYSTAL OF SULPHATE OF MAGNESIA.

Alums.—The alums constitute an isomorphous group of sulphates of alumina and of the alkalies, magnesia, iron and manganese, each member of which crystallizes in the Regular system, with 24 molecules of water. Some of the more important members of the group are the following:

Potash alum, $K_2SO_4 + Al_2(SO_4)_3 + 24H_2O$.
Soda-alum, $Na_2SO_4 + Al_2(SO_4)_3 + 24H_2O$.
Ammonia-alum, $(NH_4)_2SO_4 + Al_2(SO_4)_3 + 24H_2O$.

These salts are easily soluble in water, and have a sweetish astringent taste.

Although the alums exist in small quantities as natural efflorescences, the alum of commerce is chiefly prepared from a mineral known as *alum-stone* (a hydrous sulphate of alumina and potash) and from aluminous shales containing pyrites, the latter mineral supplying the sulphuric acid.

Phosphates.

The only phosphates of commercial importance are those of lime, known variously as apatite, phosphorite, coprolites, and phosphatic chalk.

They are used in agriculture for the improvement of soils.

Apatite.—Hexagonal, occurring in short prisms or in thick tablets. The smaller crystals are usually colourless and glassy in appearance, and present numerous faces, namely, pyramids and prisms, usually terminated by the basal plane; but it also occurs in large opaque crystals, and in compact or fibrous nodular masses. The latter is the variety known as *phosphorite*. It is sometimes white, but is usually tinted green, blue, violet, or red, and has a greasy lustre.

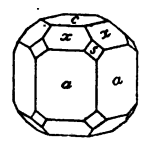


FIG. 103.—APATITE.
c, basal plane.
x, proto-pyramid.
s, deutero-pyramid.
a, proto-prism.

Apatite possesses two cleavages, basal and prismatic, both imperfect. Its hardness is 5; specific gravity, 3·16 —3·22. Chemically it is a phosphate of lime with fluoride or chloride of lime. The fluorine variety contains 42·26 per cent. of phosphoric acid, and 3·77 per cent. of fluorine, while the chlorine variety contains 40·92 per cent. of phosphoric acid, and 6·82 per cent. of chlorine.

Apatite is found in Cornwall, Spain, Germany, Russia, the United States and Canada.

Coprolites—are nodules composed of impure phosphate of lime, which are supposed to be the fossil excrementa of fishes. They are found in several formations, notably in the Carboniferous (Scotland), Gault, Upper Greensand, and in the Coralline and Red Crags, constituting a valuable source of artificial manure.

Phosphatic Chalk.—Certain beds of the Chalk formation in Belgium are phosphatic, and are extensively worked as a source of artificial manure. A similar deposit has recently been discovered in this country at Taplow.

Other Useful Minerals.

(non-metals.)

Sulphur.—Crystallizes in the Rhombic system, the habit of the crystals being pyramidal. It also occurs in nodular, kidney-shaped or stalactitic masses, or as a mealy deposit or incrustation. Hardness, 1·5—2·5; specific gravity, 1·9—2·1. Colour, pale yellow to dark brown.

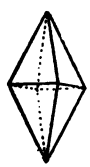


FIG. 104.—SULPHUR. Rhombic pyramid.

Chemically it consists entirely of the element sulphur, and is produced by sublimation in volcanic districts or by deposition from sulphureous springs.

Graphite—is considered on crystallographic grounds to be monoclinic, although its six-sided crystals have a

decidedly hexagonal habit. Most frequently it occurs massive, or in scales disseminated through rocks. Hardness, 0·5—1; specific gravity, 1·9—2·3. Colour black, but with silvery metallic lustre. Unctuous to the feel, soiling the fingers. Chemically, graphite consists of pure carbon. It occurs in scales disseminated through limestones, slate, mica-schists, or in larger pocket-like deposits and veins, when it is worked as a source of "black-lead" or plumbago. It is found in Borrowdale near Keswick in the Lake District, in Finland and Siberia, and in the United States and Canada.

Among the most valuable of mineral products are the different varieties of *Coal*, *Asphalt*, *Petroleum*, *Ozokerite* (*Paraffin*), *Elaterite*, etc., etc., which are compounds of carbon with hydrogen, and, in the case of coal and asphalt, oxygen. They are amorphous, in part liquid or semi-liquid masses, resulting primarily from the decomposition of organic matter.

IV. GEMS OR PRECIOUS STONES.

Under this head are included certain minerals of considerable beauty and rarity (and consequently of great value) which are used for the purpose of ornamentation and personal adornment.

The two chief physical features in a precious stone are *hardness* and *brilliancy*. While the former insures durability by preventing deterioration under wear, it is the latter which determines the beauty of the gem-stone. But brilliancy is produced by a combination of properties which may be variously developed in a stone. These properties are the refractive index, dispersive power, pellucidity, colour, and pleochroism.

The *refractive index* determines the amount of light which undergoes total reflection from the facetted surfaces of a gem, and thus materially influences its lustre. The "adamantine" lustre of the diamond and other stones is the result of a high refractive index.

By *dispersive power* is meant the resolution of a ray of white light into its component colours, in passing from one medium to another. This is due to each coloured ray having an index of refraction differing from that of the other colours for any particular medium. The greater the difference, the greater the dispersive power. The quality of emitting brilliant flashes by varying colour, which is embraced in the term "fire" applied to certain gem-stones, is a phenomenon of dispersion.

Pellucidity.—Although most gems are perfectly limpid, a few are only translucent or opaque (opal, turquoise, etc.).

Colour.—The pure and delicate colours possessed by

gems are a great feature in their beauty, and in some cases constitute the sole distinction between stones of identical composition which have received different appellations. Thus the ruby and the sapphire are red and blue varieties respectively of the mineral corundum; and the emerald and the aquamarine are green and blue varieties of beryl.

Pleochroism is the property, possessed in greater or less degree by many gems of transmitting differently coloured light when viewed in different directions.

The determination of the *specific gravity* is of great use in distinguishing precious stones of similar appearance.

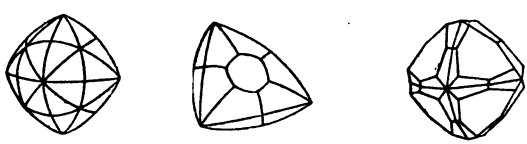


FIG. 105.—ROUNDED CRYSTALS OF DIAMOND.

Diamond—crystallizes in the Regular system, the usual form being the octahedron alone, or this form in combination with the rhombic dodecahedron and other regular forms. The faces are generally curved, producing rounded crystals. This precious stone possesses a perfect octahedral cleavage and conchoidal fracture, while optically it presents a high refractive and dispersive power, producing brilliant lustre, and "fire" or "play of colours." It is the hardest of all minerals, topping the scale with 10. Specific gravity, 3·5—3·6. Although generally colourless, it is also found yellow, straw-coloured, or brown, and very occasionally green and blue.

Chemically it is pure carbon, yielding carbon dioxide when burnt in oxygen. Diamonds are found in alluvial sands, in association with other precious stones, and with gold and platinum,—in the Deccan of India, Brazil (Minas Geraes), Borneo, Sumatra, and Australia. The chief source of the present supply is at Kimberley, in South Africa, where stones of the first water and of good size are found imbedded in a green, tufaceous material, apparently filling volcanic vents or necks.

The following list gives the names and weights of the largest and most famous diamonds whose discovery has been recorded. The weight is given in carats (one carat = 3·17 grains), and in most cases is that of the cut stone.[1]

	Carats.	
	In the rough.	When cut.
Mattam	367	—
Nizam	340	—
Stewart	288⅜	—
Great Mogul	787½	279½
Star of the South	254½	125
Dutoit I.	—	244
Great Table	—	242¼
Jägersfontein	209¼	—
Regent	410	136⅞
Austrian Yellow	—	139½
Portuguese Regent	—	215
Koh-i-nûr	193	102¾
Porter Rhodes	150	—

[1] For this table I am indebted to A. H. Church's "Precious Stones." (Chapman and Hall, London.)

Corundum—crystallizes in the Hexagonal or Rhombohedral system, being isomorphous with specular iron ore. It forms six-sided pyramids or prisms, terminated by the basal plane, the habit being tabular or barrel-shaped. The basal plane is characterized by three systems of parallel lines, intersecting at an angle of 60°. Rounded crystals are often found loose, in rolled pebbles and grains. The cleavage is both basal and rhombohedral. Hardness, 9; specific gravity, 3·9—4. Chemically, corundum is alumina, the composition of which is represented by

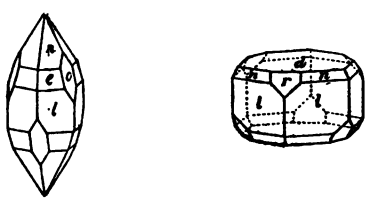


FIG. 106.—CORUNDUM: CHARACTERISTIC CRYSTALS.

d, basal plane.
r, rhombohedron (R).
o, rhombohedron (−2R).
n, deutero-pyramid ($\frac{4}{3}$P2).
e, deutero-pyramid ($\frac{8}{3}$P2).
l, deutero-prism.

the formula Al_2O_3, which is equivalent to 53·04 per cent. of aluminium, and 46·96 per cent. of oxygen.

The colour of these stones is very variable. Among jewellers the pellucid varieties are known by the following names, according to colour: *sapphire*, blue; *ruby*, red (pigeon's blood); *oriental topaz*, pale yellow; *oriental amethyst*, purple.

Sapphires are found in Burmah and Ceylon; also imbedded in the basalts of the Rhine.

The ruby when of perfect colour is of far greater

value than the diamond. The best stones are brought from Burmah, where they occur in a matrix of calcite.

The oriental topaz and oriental amethyst are also stones of considerable value.

Beryl—crystallizes in the Hexagonal system, forming long six-sided prisms, terminated by the basal plane. In addition pyramidal faces are sometimes developed. The prismatic planes usually show a vertical striation. Basal cleavage. Fracture, conchoidal to uneven. Hardness, 7·5—8; specific gravity, 2·70—2·76.

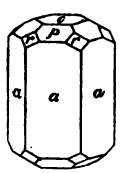


FIG. 107.—BERYL.
c, basal plane.
P, pyramid.
a, prism.
r, deutero-pyramid (2P2).

Beryl is transparent to translucent, and possesses a vitreous lustre. In colour it varies from colourless, through various shades of yellow and green, to blue. Chemically, it is a silicate of beryllia and alumina, being represented by the formula $3BeO, Al_2O_3, 6SiO_2$, with 67 per cent. of SiO_2, 19 per cent. of Al_2O_3, and 14 per cent. of BeO.

The emerald-green to apple-green variety is known as *emerald*, while the blue or sea-green variety is distinguished as *aquamarine*.

The crystals are found imbedded in gneiss, granite, mica-schist, limestone and clay slate, in the Ural Mountains (Mursinka, Katharinenburg, and Miask), the Altai, New Granada (Muzo), and Brazil.

Chrysoberyl—known to the jewellers under the name of the *cat's-eye* (*cymophane*) and *oriental chrysolite*.

Crystallizes in the Rhombic system, in forms similar

to those of olivine. Often in twins and trins, the latter being known as *Alexandrite*, which was once considered to be a distinct mineral. The habit of the crystals is short prismatic or thick tabular, with vertical striations. Imperfect cleavage. Conchoidal fracture. Hardness, 8·5; specific gravity, 3·65—3·8. Colour, greenish-white to olive-green; vitreous lustre. The variety known as cat's-eye shows a remarkable asterism or chatoyancy, from which it derives its name. Chemically, chrysoberyl is a compound of beryllia with alumina, namely, BeO, Al_2O_3, with 19·72 of BeO and 80·28 per cent. of Al_2O_3.

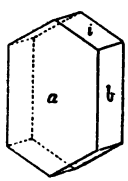


FIG. 108.—CHRYSOBERYL.
a, macro-pinacoid.
b, brachy-pinacoid.
i, brachy-dome.

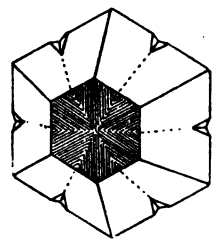


FIG. 109.—COMPOUND TWINNED CRYSTAL (ALEXANDRITE).

It is chiefly found in Brazil, Ceylon, Ural Mountains, and in Connecticut in the United States.

Topaz.—Rhombic; the crystals having a prismatic habit, and being terminated by the basal plane alone or together with faces of various brachy-domes, and those of the proto-pyramid. One end alone shows perfect development, the faces constituting the opposite termination being usually rudimentary. The prisms show a vertical striation. Very perfect basal cleavage. Hard-

ness, 8; specific gravity, 3·51—3·57. Vitreous to adamantine lustre; colourless, pale straw colour to sherry-yellow. A rose-pink colour is produced by

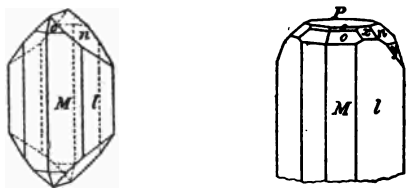


FIG. 110.—TOPAZ.

P, basal plane. *M*, prism.
s and *o*, pyramids. *l*, brachy-prism.
x, brachy-pyramid. *n* and *y*, brachy-domes.

heating the stone. The colours become bleached by long-continued exposure to strong daylight.

Chemically, topaz is a compound silicate and silcofluoride of alumina: $5Al_2SiO_5 + Al_2SiF_{10}$, corresponding to 33·22 per cent. of silica, 56·54 per cent. of alumina, and 17·61 per cent. of fluorine.

It occurs in drusy cavities of granitic rocks, or in loose and rolled pebbles, at St. Michael's Mount in Cornwall, the Mourne Mountains in Ireland, Brazil (Minas Geraes), United States, Siberia, Ceylon.

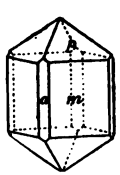


FIG. 111.—ZIRCON.

P, pyramid.
m, prism.
a, deutero-prism.

Zircon—Crystallizes in the Tetragonal system, being isomorphous with tinstone. The crystals are prismatic or pyramidal in habit. The prisms are of both orders, but are terminated by pyramids of the

first order. Conchoidal to uneven fracture. Hardness, 7·5; specific gravity, 4·4—4·7. Brilliant, almost adamantine lustre, and high dispersive power. The colours are rich and delicate, varying from red through brown, yellow, green, to deep indigo blue.

In composition, zircon is a silicate of zirconium: $ZrSiO_4$, *i.e.*, 67·03 per cent. of ZrO_2, and 32·97 per cent. of SiO_2.

The varieties which are valued as gems, are termed *jargoon* and *hyacinth*. Zircon is a constituent of most granites, syenites, etc., and of the sands, etc., derived from their decomposition. The precious varieties are found chiefly in Ceylon, and at Mudgee in New South Wales. A fine red variety comes from Espaily, in the Auvergne, France.

Garnet—crystallizes in the Regular system, the usual forms being the rhombic dodecahedron and the icositetrahedron, either alone, or in combination.

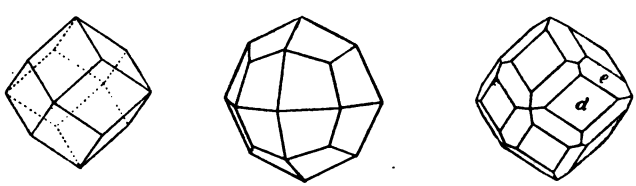


FIG. 112.—GARNET.

Common forms, rhombic dodecahedron, icositetrahedron, alone and in combination.

The garnets vary greatly in their physical properties and in chemical composition. Their fracture is conchoidal, or irregular and splintery. They have a vitreous

to greasy lustre, and are transparent to opaque. The hardness varies from 6·5 to 7·5; specific gravity, from 3·4 to 4·3. In Uwarowite the latter is as low as 3·15. According to chemical composition, the chief varieties of garnet may be classified thus:

1. *Lime-Alumina Garnet.*—Essonite, or Cinnamon-stone. Colour, golden-yellow, or honey-coloured. Silicate of lime and alumina. Found in Ceylon.

2. *Iron-Alumina Garnet.*—Almandine and Carbuncle. Colour, violet to amethystine purple, or crimson to brownish-red. Silicate of iron and alumina. Found as a constituent of numerous rocks.

3. *Magnesia-Iron-Lime-Alumina Garnet.*—Pyrope or Bohemian Garnet. Colour, a beautiful blood-red or dark crimson. Silicate of the above-mentioned oxides. Found associated with serpentine in Bohemia; also at Santa Fé in New Mexico.

4. *Lime-Iron Garnet.*—Melanite. Colour, black. Found as a volcanic product at Frascati near Rome, and as a rock-constituent in many places.

5. *Lime-Chromium Garnet.*—Uwarowite. Colour, a beautiful emerald-green. Found in the Ural Mountains, in association with chrome-iron ore, and in Canada.

Many other minerals are used as gems, of which space will not allow more than a brief mention.

Spinel—is a double oxide of aluminium and magnesia, crystallizing in the Regular system. Hardness, 8; specific gravity, 3·5—4·1. It is known to the jewellers under the name of the *spinel-ruby* or *Balas-ruby*.

Tourmaline,—a complicated silicate and borate of alumina, magnesia, and iron, crystallizing in the Rhombohedral system. Hardness, 7—7·5; specific gravity,

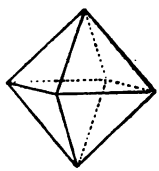


FIG. 113.—SPINEL.
Octahedron.

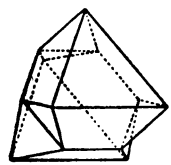


FIG. 114.—SPINEL.
Crystal twinned on an octahedral face.

2·94—3·24. The pellucid green, blue, and red varieties are sometimes used as gems. The stones are recognizable by a pronounced dichroism.

Peridot or **Chrysolite,**—a beautiful transparent, deep olive-green variety of olivine (see p. 54)—is used as a gem-stone.

Opal—is the amorphous hydrated variety of silica. Hardness, 5·5—6·5; specific gravity, 1·9—2·3. It possesses a bluish, yellowish, or milky colour, and is translucent. The "fire" of "precious opal" is the result of reflection and diffraction of light from internal surfaces.

Turquoise or **Callaite**—is a hydrated and basic phosphate of alumina, occurring in amorphous masses and veins in eruptive rocks. Hardness, 6; specific gravity, 2·62—2·8. It is opaque and possesses a fine cerulean or peacock-blue colour.

The Cutting of Gem-Stones.

The beauty of finished gems is greatly dependent upon the way in which they have been treated by the lapidary. The facetting or "cutting" of a gem consists in grinding away the superfluous portions on a flat revolving wheel, carrying diamond dust. When the required facets have thus been obtained, they are brought to a high state of polish by a careful and exact abrasion, under a practised hand. The form which the cut stone is made to acquire depends partly on its shape "in the rough," partly on the judgment of the lapidary. The form usually given to a well-shaped diamond is the **brilliant**. It is a mode of cutting eminently fitted to display the fine qualities of this much-prized gem. The brilliant, of which a plan and section is shown in fig. 115, may be described as a double pyramid, the top half of which is truncated by a large plane surface, known as the *table*, while the bottom half is terminated by a small plane known as the *culet*. The middle edge of the double pyramid is termed the *girdle*, and is the part which is held by the setting.

Another mode of cutting is the **rose**. In this form there is a circular or elliptical flat base, surmounted by a low facetted pyramid. In the **step-cut**, which is chiefly used for emeralds and other coloured stones, the facets are arranged in parallel steps, there being two or three steps between the table and the girdle, and a greater number dependent on the nature of the stone, between the girdle and the terminal culet. The portion above

the girdle is sometimes facetted, producing the **mixed** or **brilliant-top** cut.

The **table** cut is used only for very flat, thin stones,

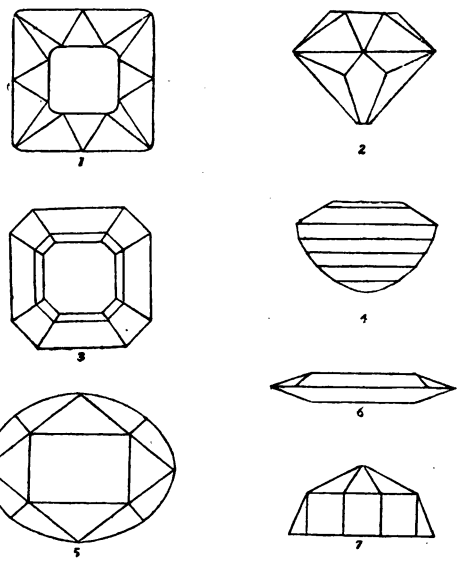


FIG. 115.—MODES OF CUTTING GEM-STONES.

1. Brilliant, viewed from above.
2. Brilliant, side view.
3. Step-cut, viewed from above.
4. Step-cut, side view.
5. Table-cut, viewed from above.
6. Table-cut, viewed from above.
7. Rose-cut, side view.

the size of which would be very considerably diminished by any other mode of cutting. It consists of two parallel plane surfaces, bounded by a bevelled edge.

There may be some among those that have read through the foregoing pages who wish to continue their study of mineralogy, or of some one of its branches, beyond the narrow limits which have of necessity been here imposed. To such the following list of small text-books, suitable for this purpose, will be of some assistance.

F. Rutley: Mineralogy (T. Murby, London). A useful pocket work of reference.

A. de Lapparent: Précis de Minéralogie (F. Savy, Paris).

E. S. Dana: A Text-book of Mineralogy (J. Wiley, New York).

H. P. Gurney: Crystallography (Society for the Promotion of Christian Knowledge, London).

G. H. Williams: Elements of Crystallography (Macmillan and Co., London).

F. H. Hatch; Introduction to the study of Petrology (Swan Sonnenschein and Co., London). For the rock-forming minerals and their mode of aggregation.

J. A. Phillips: Ore-deposits (Macmillan and Co., London). For the mode of occurrence of the ores.

Warington W. Smyth: Coal and Coal-mining (Crosby, Lockwood and Son, London).

A. H. Church: Precious Stones (Chapman and Hall, London).

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